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IRRADIATION AS AN ALTERNATIVE FOR DISINFECTION OF DOMESTIC WASTE IN THE CANADIAN ARCTIC

by

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for

Canada Mortgage and Housing Corporation

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ABSTRACT

The purpose of this study was to evaluate the technical and economic feasibility of various methods for disinfecting wastewater in the Canadian Arctic with specific reference to gamma radiation. More conventional disinfection practices, such as chlorination, chlorination-dechlorination, and ozonation were compared to gamma radiation along with ultraviolet (UV) irradiation and lime (pH) disinfection.

The quality of lagoon effluent, highly diluted (weak) sewage, holding tank wastes and honey-bag wastes, which are the typical waste types found in northern communities, was established from data available in the literature. Further literature reviews were undertaken to establish a data base for design and effectiveness of disinfection systems operated in cold climates.

Capital and operating costs for all technically feasible disinfection process alternates were estimated based on historical cost data adjusted to 1977 for the construction and installation of similar systems in the north. The costs of equipment, chemicals, fuel and electrical power were obtained from suppliers.

The environmental impact of each of the disinfection processes was reviewed with emphasis on gamma irradiation. Safety and health aspects were also considered.

The study concluded that gamma irradiation was capable of providing safe, reliable disinfection for concentrated honey-bag and holding wastes. Pilot-scale testing was recommended prior to construction of full-scale disinfection facilities. For lagoon effluents and weak sewage, gamma irradiation was not cost competitive with other alternates; rather chlorination-dechlorination was found to be the most cost-effective and environmentally acceptable alternative.

RÉSUMÉ

Cette étude avait pour but de comparer l'efficacité technique et économique de diverses méthodes de désinfection des eaux usées dans l'Arctique canadien, notamment par l'irradiation aux rayons gamma. Des méthodes traditionnelles telles la chloration, suivie ou non de déchloration, et l'ozonation ont été comparées à l'irradiation aux rayons gamma et aux rayons ultra-violets et à la désinfection à la chaux.

Nous avons établi, à partir de documents publiés sur le sujet, la qualité des effluents du lagunage, des eaux usées fortement diluées, des déchets en bassins intercepteurs et de ceux des "sacs à miel", déchets caractéristiques des localités nordiques. Des recherches bibliographiques plus poussées ont permis de réunir des données sur la conception et l'efficacité des dispositifs de désinfection utilisés dans les climats froids.

Nous avons estimé les dépenses de capital et d'exploitation des diverses méthodes techniquement réalisables de désinfection à partir des coûts précédents de construction et de mise en place de dispositifs similaires dans le Nord, ramenés à 1977. Les coûts du matériel, des produits chimiques, du combustible et de l'électricité ont été obtenus des fournisseurs.

Nous avons aussi étudié les répercussions sur l'environnement des diverses méthodes de désinfection. On n'a pas oublié non plus les aspects de la santé et de la sécurité.

Les recherches ont démontré que l'irradiation aux rayons gamma des "sacs à miel" et des déchets en bassins intercepteurs était sûre et fiable. On recommande la poursuite d'essais en unité-pilote avant la construction d'installations à l'échelle. La méthode, en comparaison avec les autres, n'est cependant pas rentable pour ce qui est de la désinfection des effluents du lagunage et des eaux usées diluées. En ces cas, la chloration suivie d'une déchloration est la méthode la plus économique et la plus valable du point de vue de la protection de l'environnement.

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CONCLUSIONS AND RECOMMENDATIONS

1) On the basis of the information contained in this report for the four types of waste investigated, the following points have been established:

Honey-Bag Wastes: The application of lime directly to disposal pits offers the most economical and only practical alternative if the disinfection of honey-bag wastes is required. The annual costs of gamma irradiation, chlorination (Purifax System), and the pumped lime system described are unreasonably high for a small community.

Holding Tank Wastes: Gamma irradiation is the most cost-effective of the methods examined for the disinfection of holding tank wastes. It is the preferred method if disinfection is the only objective. The application of lime reduces the effluent BOD and suspended solids in addition to achieving disinfection. Consequently, if disinfection of holding tank wastes is likely to be provided in the future, pilot facilities for both lime and gamma irradiation should be evaluated.

Weak Sewage: If adequate disinfection for weak sewage is to be provided, equalization of sewage flow and strength would be required. Chlorination - dechlorination is the most cost-effective, environmentally acceptable method of disinfection for weak sewage.

Lagoon Effluents: From a cost standpoint, ultraviolet (UV) disinfection of lagoon effluents is the most effective of the alternatives for low bacterial kill (less than 99 percent) providing suitable effluent quality can be obtained. The application of UV would be severely limited by both the inconsistent disinfection and the larger equipment and operating cost required for higher bacterial kills. Chlorination-dechlorination appears to be the most cost-effective, environmentally acceptable disinfection alternative for lagoon effluents.

2) Gamma irradiation as a disinfection alternative is a reliable and environmentally acceptable process. The process was judged to be cost-effective only for disinfection of concentrated holding tank wastes. No evidence of increased mutation or production of radioactive by-products has been associated with gamma disinfection. As little pilot or full scale data are available on disinfection of wastewater, pilot

facilities should be constructed and fully evaluated prior to consideration of a full scale irradiation disinfection facility for holding tank wastes.

3) In comparing total annual disinfection costs in the Baffin (eastern) and Inuvik (western) regions of the Arctic, it was found that the costs for similar effluents were relatively independent of location because the use of pre-assembled, modular components resulted in relatively low labour and construction costs, both of which are geographically dependent. The differences in estimated costs were related directly to the Northern Community Index. It appears possible to factor disinfection costs in different locations using the NCI, although this approach should be used with caution.

4) The comparison of total annual disinfection costs for lagoon effluents in the Arctic with those in southern Canada indicates that costs would be about two times higher in the Arctic.

1 INTRODUCTION AND TERMS OF REFERENCE

1.1 Background

The 1972 census figures show there are 43 communities in the Northwest Territories with populations in the range of 100 to 1000, and seven communities with populations exceeding 1000. Based on water supply and sewage treatment data (Water and Pollution Control, 1977), five large communities in the Northwest Territories are served by conventional water and sewer systems. The remaining population, which is largely native, utilizes honey-bags and holding tanks for waste disposal. Low receiving water temperature lengthens the survival time of pathogens and parasites thus increasing the likelihood of infection and public health problems. With greater activity in the Arctic regions, more emphasis on public health protection will be required.

Environment Canada's 1974 interim guidelines for wastewater disposal in northern Canadian communities establish schedules for waste treatment processes. Total and fecal coliform guidelines are also tabled. The proposed treatment schedule does not require that communities in the Northwest Territories disinfect treated domestic wastewaters, although it is likely that disinfection will be required in the future.

Accordingly, this study focuses on the costs of alternative forms of disinfection of domestic wastes under Arctic and subarctic conditions north of the 60th parallel. The successful pilot demonstration of gamma irradiation for disinfection at the Burlington Skyway Water Pollution Control Plant (Murphy, 1974; Vajdic, 1974) has generated an interest in the application of gamma irradiation for northern Canadian communities. The Burlington study provides the data from which to demonstrate the applicability of irradiation and compare costs with other forms of disinfection including chlorination, chlorination-dechlorination, ozonation, UV irradiation, and lime disinfection, based on the destruction of the coliform indicator organism.

1.2 Study Objective

The overall objective of this study was to compare the technical and economic feasibility of gamma irradiation with conventional effluent disinfection processes for the four wastewater types identified as typical in the Canadian Arctic. The following specific tasks were undertaken to achieve the overall objective:

1) Three northern communities representative of those communities discharging lagoon effluent, weak sewage, holding tank wastes and honey-bag wastes were selected.

2) The four wastewaters were characterized with respect to total coliform counts, BOD, suspended solids and alkalinity.

3) For the four types of wastewaters, process designs for each disinfection alternative were prepared. These had to be both technically feasible and meet the disinfection levels determined by the Environment Canada's Interim Guidelines.

4) Based on these process designs, estimates were prepared of both capital and operating costs. Capital costs were broken down into engineering, equipment, installation and construction costs. Operating costs included energy, chemicals (purchase and transport), manpower, and maintenance costs.

5) Environmental, process safety and health aspects were investigated. These included mutagenesis (gamma irradiation alternative in particular), manpower and skill require-ments, safety and handling precautions, process reliability, climatic effects, and level of development of current technology.

6) Variations in disinfection cost for representative eastern and western Arctic communities of the same size and wastewater characteristics were evaluated.

7) Disinfection costs for each alternative used in the Arctic were compared with those for a similar sized community providing secondary treatment in southern Canada.

2 WASTEWATERS FROM ARCTIC COMMUNITIES

In general, in terms of wastewater management, communities in the Canadian Arctic may be divided into two groups: large communities (i.e. more than 1000 people) now served or to be served in the future by conventional piped sewer systems; and smaller centres where trucked sewage disposal is in use (i.e. honey-bags from bucket toilets or holding tank pump-outs are employed).

Currently, the larger communities which use sewers (e.g. Inuvik, Yellowknife, Fort Smith, and Hay River) provide either secondary treatment in continuous flow long detention lagoons, or primary treatment in short detention continuous flow lagoons. Of those communities served by piped sewer systems, most make use of systems similar to southern Canadian piped water systems which are either buried or in utilidor. Others make use of a "bleeder" water system with continuous discharge to prevent pipe freeze-up, resulting in weak or diluted sewage as is the case at Whitehorse and Dawson.

Until recently, most smaller Arctic communities have relied on honey-bags for disposal of human waste. With the advent of regular trucked water delivery, conversion to holding tanks with regular pump-outs is being implemented as older housing units are being phased out in each community. However, the use of the honey-bag is likely to continue for up to 20 years. Heinke and Prasad (1976) have recommended that honey-bag wastes be disposed of at a separate waste pit which would be covered and abandoned on an annual basis rather than disposed of at relatively uncontrolled dump sites as is common at present. Similarly, holding tank wastes would be discharged to a controlled holding lagoon, from which liquid effluent would then be periodically discharged to a water course. The former practice was to discharge holding tank wastes to dumps along with honey-bag wastes. In order to provide adequate disinfection, controlled disposal systems for honey-bag and holding tank wastes would be required. Table 1 below summarizes the waste types and treatment systems evaluated in this study.

Inuvik in the MacKenzie River delta, was selected as representative of a larger community served by a sewer system and waste treatment system, while nearby Aklavik was selected as representative of the smaller, unsewered community. The selection of a larger and smaller community in the same geographic region allowed direct assessment of the effect of community size since the effect of transportation on costs would be the same in each case. Dawson, in the Yukon, was selected as a community representative of the "bleeder" type water system (Dawson is in a different transportation corridor, and could be regarded as "subarctic").

TABLE 1 WASTEWATER TYPES AND REPRESENTATIVE COMMUNITIES

Wastewater Type	Collection/Treatment System	Representative Community	Population Served
Lagoon Effluent	sewer/lagoon	Inuvik	2500
Weak Sewage	sewer/no treatment	Dawson	530
Holding Tank and Honey-Bag Wastes	tank truck/no treatment	Aklavik	675

As most communities in the eastern Arctic discharge wastewaters directly to the ocean, where adequate dilution can be provided, the need for disinfection was considered to be relatively low leading to the selection of western communities where disinfection is more apt to be required. To broaden the base of the study and to illustrate further the effects of different transportation systems, Frobisher Bay and Pangnirtung (in south Baffin Island) were selected for comparison with Inuvik and Aklavik.

It is not the intention of this report to identify a specific need for disinfection at any of the communities selected, nor to provide detailed design information required for the construction of such a disinfection system.

3 WASTEWATER CHARACTERISTICS

3.1 Bacteriological Populations in Feces, Sewage and Effluents

As a basis to establish the bacterial kill required for adequate disinfection, the available literature on bacterial populations in human wastes, sewage, and treated effluents was reviewed. Specific data on coliform populations in the Inuvik lagoon effluent and in Dawson weak raw sewage were available, while the coliform populations of holding tank effluents and honey-bag wastes were estimated from public health data on human wastes.

The data on the "normal" coliform levels in human wastes are summarized in Table 2. The total coliform production in human feces ranged from 2×10^9 to 4.7×10^{10} per person per day, with a median value of 7×10^9. These results confirm the per person total coliform production calculated from the data for the community of Dawson reported by Heinke and Baldwin (1973).

TABLE 2 SUMMARY OF INDICATOR ORGANISM CONCENTRATIONS IN HUMAN WASTE

Coliforms per Person per Day in Feces			
Total Coliform	Fecal Coliform	Fecal Streptococci	Reference
1.95×10^9	--	--	Clark et al (1964)
3×10^{10}	--	--	Grabow (1970)
2.1×10^9	--	--	Senn (1961)
--	--	4.5×10^8	Kenner et al (1960)
2.2×10^{10}	0.9×10^{10}	2.2×10^{10}	Geldreich et al (1964)
4.7×10^{10}	--	--	Heinke and Prasad (1976)

At Inuvik, Heinke et al (1972) reported a median total coliform count of 1.0×10^5/100 mL in the lagoon effluent under winter conditions. This value was substantially higher than the summer value of 6.8×10^3/100 mL, due to a lower winter coliform death rate and was therefore used as the basis for calculating required bacterial kills. The range of values reported for the Inuvik lagoon effluent in winter was 1.0×10^4/100 mL to 6.3×10^5/100 mL. The median total coliform value of 1.0×10^5/100 mL selected for design purposes agrees with a value of 2.85×10^5/100 mL

reported by Geldreich et al (1964) for a waste stabilization basin operated year-round in the mid-west United States.

At Dawson, Heinke and Baldwin (1973) reported total coliform counts in the weak raw sewage discharged from Dawson to the Klondike River ranging from 1.5×10^3/100 mL to 1×10^7/100 mL. The median (geometric mean) value was 1.0×10^5/100 mL, which is approximately the same strength as the Inuvik lagoon effluent, although the range is much wider. The wider range is probably the result of the normal diurnal fluctuations which would not appear in a lagoon effluent. For purposes of designing disinfection facilities the median value was assumed. Using the median per person flow value of 5 915 L/person•d, this amounts to a daily per person production of 5.9×10^9 coliforms per day.

For Aklavik, total coliform concentration in honey-bag and holding tank wastes were estimated from the total coliform production data above, and the waste volumes reported in the literature. Based on public health data for daily human waste volumes, Heinke and Prasad (1976) estimated a daily waste volume of 1.3 L/person•d for honey-bag wastes. When the median value of 7×10^9 total coliforms per person per day is assumed, an estimated median total coliform count of 5.4×10^8/100 mL in honey-bag wastes results.

Wastewater volumes for holding tanks were estimated from the honey-bag data of Heinke and Prasad (1976) and recent data on water usage supplied by the Northern Technology Unit (NTU) of Environment Canada. Based on the NTU data, holding tanks are expected to receive approximately 68 L/person•d of waste once the conversion to pressure water systems and low water usage toilets in each housing unit is complete. The holding tank will also receive "grey" water such as kitchen wastes and wash water. As most of the BOD and suspended solids and essentially all of the coliform bacteria will result from human waste, the holding tank waste characteristics were calculated using the honey-bag waste characteristics with a dilution ratio of 68:1.3.

The total coliform counts (Table 3) were used in the process designs for the various disinfection alternatives. Concentrations of fecal coliforms and fecal streptococci have not been included in the designs, as the disinfection data in the literature for the various processes were not complete for these indicator organisms. Comparison of the effectiveness of the various disinfection options was therefore not possible for these organisms. A study of the correlations between indicator organisms and pathogens was beyond the scope of this investigation.

TABLE 3 SUMMARY OF WASTEWATER CHARACTERISTICS FOR DISINFECTION PROCESS DESIGN

Waste Type	Population Served	Flow (L/person•d)	Total Coliform Count/100 mL	BOD (mg/L)	Suspended Solids (mg/L)	pH	Alkalinity (mg/L as $CaCo_3$)	Typical Municipality
Lagoon Effluent	2500	545	1.0×10^5 (1×10^4 - 6.3×10^5)	50 (20-80)	20 (10-30)	7.3 (6.6-8.0)	110 (75-145)	Inuvik
Weak Sewage	530	5915	1.0×10^5 (1.5×10^3 - 1.10^7)	15 (0-25)	15 (2-380)	- (5.3-8.4)	24.4 (10-46)	Dawson
Honey-Bags	675	1.3	$\sim 5 \times 10^8$ (1.5×10^8 - 2.3×10^9)	$\sim$ 37 000*	38 850	8.8	15 000	Aklavik
Holding Tank Effluent	675	68	1×10^7 (3×10^6 - 4×10^7)	700**	750	8.5**	300**	Aklavik

* Calculated by Heinke and Prasad (1976)
** Calculated on basis of honey-bag wastes diluted 1.3 to 68

3.2 Sewage and Effluent Strengths

A summary of wastewater characteristics for disinfection process design at Inuvik, Dawson and Aklavik is presented in Table 3. The data for the Inuvik lagoon reflect the median waste strength of the lagoon effluent under winter operating conditions as reported by Heinke et al (1972). The data for Dawson were taken from the work of Heinke and Baldwin (1973). The flow value for Dawson was given as the mid-point of the reported flow range (5000 to 6825 L/person•d). The honey-bag wastes characteristics at Aklavik were taken from Heinke and Prasad (1976) and represent the mean values reported. The data for the holding tank wastes were estimated assuming dilution of honey-bag wastes from a total volume of 1.3 to 68 L/person•d to account for flushing water, wash water and kitchen wastewater.

For purposes of process design it was assumed that the entire population of Aklavik is served exclusively by a honey-bag system or by a holding tank system. Combinations of the two systems have not been considered.

3.3 Bacterial Criteria for Effluents

In 1974, the Water Pollution Control Directorate (WPCD) of Environment Canada published "Interim Guidelines for Wastewater Disposal in Northern Canadian Communities". The guidelines for disinfection of treated wastewater before discharge to the receiving waters are summarized below:

a) In waters used for water supply, drinking, culinary and food processing without the need for treatment other than simple disinfection and simple removal of naturally present impurities, the mean of five or more samples in any one month should have a total coliform density not exceeding 50 per 100 mL and a fecal coliform density less than 2 per 100 mL.

b) In waters used for direct contact recreation, stock water and other agricultural and industrial uses when worker contact is unavoidable, the mean of five or more samples in any one month should have a total coliform density not exceeding 1000 per 100 mL and a fecal coliform density not exceeding 200 per 100 mL.

c) In waters to be withdrawn for treatment and distribution as a potable supply or used for outdoor recreation other than direct contact, 80 percent of at least five samples taken in any one month should have a total coliform density not exceeding 5000 per 100 mL. The upper permissible limit should be set on case-by-case basis by the regulatory authority.

In addition to the above points, where chlorine is used as the disinfectant, the guidelines established a maximum chlorine residual of 1.0 mg/L after 60 minutes contact time.

The relationship between coliform densities and human health risks has not been established. The coliform limits specified in Environment Canada's report are therefore arbitrary limits established as guidelines. The intention of this philosophy is to keep the coliform counts and thereby the general bacteria counts as low as practical when there is human use of the water.

Gordon et al (1974) report that in the U.S. Environmental Protection Agency (EPA) Region X (Alaska) similar guidelines are applied to the effluent rather than to the receiving waters. This approach attempts to compensate for the stratification effect which results from the discharge of relatively warm effluents into cold receiving waters and which tends to reduce the rate of dilution of the effluent. This approach has been assumed for the designs in this study and represents the "worst case" for no effluent dilution.

The level of disinfection actually required will depend on the dilution available in the receiving water. For example, a lagoon effluent containing 1×10^5 coliforms per 100 mL requires only 100-fold dilution to meet Environment Canada's level b) of 1000 per 100 mL. In contrast, if only a 10-fold dilution is possible then disinfection of the effluent to 1×10^4 coliforms per 100 mL (a 10-fold reduction) is required.

The actual effluent coliform levels used for design purposes have been selected to be i) 50, ii) 500, iii) 5000 and iv) 50000 total coliforms per 100 mL. Levels i) and iii) are the same as the Environment Canada's guidelines levels a) and c). Level ii) has been set at 500 total coliforms per 100 mL so that the three levels are an order of magnitude apart and so that the organism survival ratios calculated for each of these levels will be an order of magnitude apart. The level of 50000 total coliforms has been included to illustrate the effect of dilution. For example, if 100-fold dilution is available in the receiving water, then it is necessary only to disinfect an effluent to 50000 to reach the 500 coliform per 100 mL level in the receiving water. Only total coliform organisms are used in this study.

The survival ratio, defined as the ratio of surviving organism concentration to initial organism concentration, as shown in Equation (1), is used for establishing the disinfection requirements, rather than percent kill of coliform organisms.

$$\text{Survival Ratio} = y/y_o \qquad (1)$$

where: y = bacterial (total coliform) count per 100 mL following disinfection.

y_o = initial bacterial (total coliform) count per 100 mL.

It has been stated by White (1972) that this approach lends itself more easily to the development of mathematical models of disinfection processes. Table 4 summarizes the survival ratios required for each type of waste in order to meet the four selected coliform levels in each effluent.

TABLE 4 SUMMARY OF DISINFECTION REQUIREMENTS

	Initial Total Coliform Count per 100 mL	Total Coliform Survival Ratio Required For			
		50 000 per 100 mL	5 000 per 100 mL	500 per 100 mL	50 per 100 mL
Lagoon Effluent	1.0×10^{5}	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Weak Raw Sewage	1.0×10^{5}	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Holding Tank Waste	$\sim 1 \times 10^{7}$	$\sim 5 \times 10^{-3}$	$\sim 5 \times 10^{-4}$	$\sim 5 \times 10^{-5}$	$\sim 5 \times 10^{-6}$
Honey-Bag Waste	$\sim 5 \times 10^{8}$	$\sim 9 \times 10^{-5}$	$\sim 9 \times 10^{-6}$	$\sim 9 \times 10^{-7}$	$\sim 9 \times 10^{-8}$

4 WASTEWATER DISINFECTION PROCESS DESIGNS

4.1 Chlorination and Chlorination-Dechlorination

Chlorination facilities have traditionally been designed by a "handbook" approach in which a dosage range is specified along with a minimum contact time of 15 minutes at maximum flow or 30 minutes at design flow and a residual of 0.2 to 1.0 mg/L (Water Pollution Control Federation, 1976). Residuals of 0.5 mg/L are common in southern Canada. Such designs are based on extensive experience in design and operation of wastewater chlorination facilities throughout the temperate climatic zones of the world. Unfortunately, a similar data base does not exist for disinfection in arctic regions. A basis for design of chlorination facilities to account for cold climates and the resultant increased persistence of pathogenic micro-organisms is required.

Selleck et al (1970) developed a mathematical model relating survival ratio y/y_o to the amperometric chlorine residual (c) and contact time (t) as illustrated in Figure 1. These data were obtained using a batch contacting system at 15 to 18°C. Gordon et al (1974) conducted similar research at 1°C in conjunction with evaluation of a highly baffled continuous flow chlorine contact chamber at temperatures ranging from 1°C to 20°C. The plot in Figure 1 of the batch data based on iodometric chlorine residuals obtained by Gordon et al (1974) at 1°C appears to indicate that temperature has no effect on disinfection by chlorine. The continuous flow data for 1°C from Gordon et al (1974) are also plotted on Figure 1. The difference in mixing between an ideal batch (plug flow) system and a real system apparently changed the slope of the line from -3.0 to -2.4. White (1972) reported a similar change in slope for a continuous flow back-mix reactor compared to a batch system.

The chlorine contact systems for lagoon effluent and weak sewage are based on the highly baffled system of Gordon et al (1974) and make use of their data as plotted in Figure 1 to determine chlorine residual and contact time:

$$y/y_o = (1 + 0.23\ ct)^{-2.4}$$

where:

c = amperometric chlorine residual (mg/L)

t = mean residence time (min).

An amperometric chlorine residual of 1.0 mg/L was selected to be consistent with the guidelines for wastewater disposal in northern communities (WPCD, 1974).

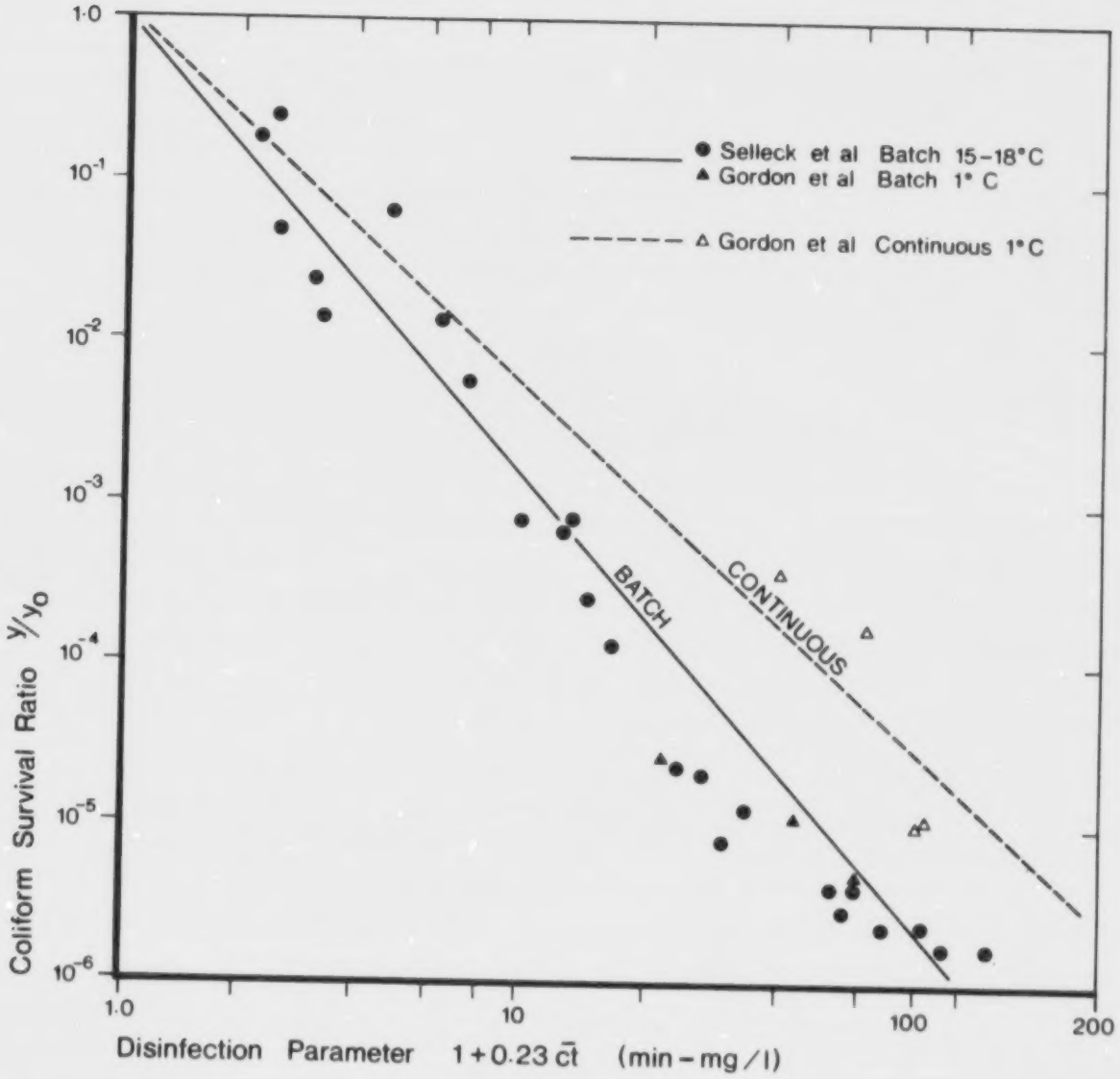


FIGURE 1 PROCESS EFFICIENCY OF WASTEWATER CHLORINATION

Selection of chlorine dosages was made on the basis of effluent quality and the dosage ranges recommended by the WPCF (1967). The designs for lagoon effluent (Inuvik) and weak sewage (Dawson) are summarized in Table 5a. As shown in the Table 5a, a slightly higher chlorine dosage has been specified for weak sewage than for lagoon effluent as the sewage is untreated and therefore would be expected to have a higher chlorine demand.

Except for size, the chlorination facilities designed for disinfection of lagoon effluent and weak sewage are the same. A schematic of the proposed system is shown in Figure 2. As indicated in Figure 2, the systems are of the solution feed type which use recycled effluent as a medium for dissolving the chlorine. As indicated in Table 5a and in Figure 2, the contact chamber has eight cells with the baffles arranged in an over-under configuration as tested by Gordon et al (1974). The dimensions used for sizing the contact chambers were those of Gordon et al (1974) scaled up to provide the specified survival ratio at average daily flow.

For chlorination-dechlorination, the chlorination system was considered to be the same as that for chlorination only, except that a higher chlorine residual was assumed (as shown in the design summary in Table 5b) to reduce contact chamber volume. Contact time to achieve a specified survival ratio decreased accordingly. Dechlorination by gaseous SO_2 was selected because the equipment required for this process is essentially identical to that for chlorination therefore minimizing maintenance work, and because the system requires little operator supervision.

Selection of SO_2 dosages was based on the stoichiometry reported by white (1972) where 0.9 mg/L of SO_2 are required per 1.0 mg/L of chlorine residual (amperometric). Normal design practice is to dechlorinate to an excess of approximately 0.5 mg/L SO_2. When an amperometric chlorine residual of 2.0 mg/L is assumed, this results in an SO_2 dosage of 2.3 mg/L.

Chlorination disinfection of holding tank and honey-bag wastes may be accomplished by the use of the Purifax process. Although this process has not been evaluated on these waste types, it was designed as a conditioning process for waste sludge prior to ultimate disposal. Bacterial destruction is claimed to be essentially complete due to the very high chlorine dosages used. Consequently, it was included in this study. The process flow schematic of the Purifax process is presented in Figure 3.

Design parameters for this process were obtained from literature supplied by the Canadian representative of the manufacturer. The chlorine requirement used for

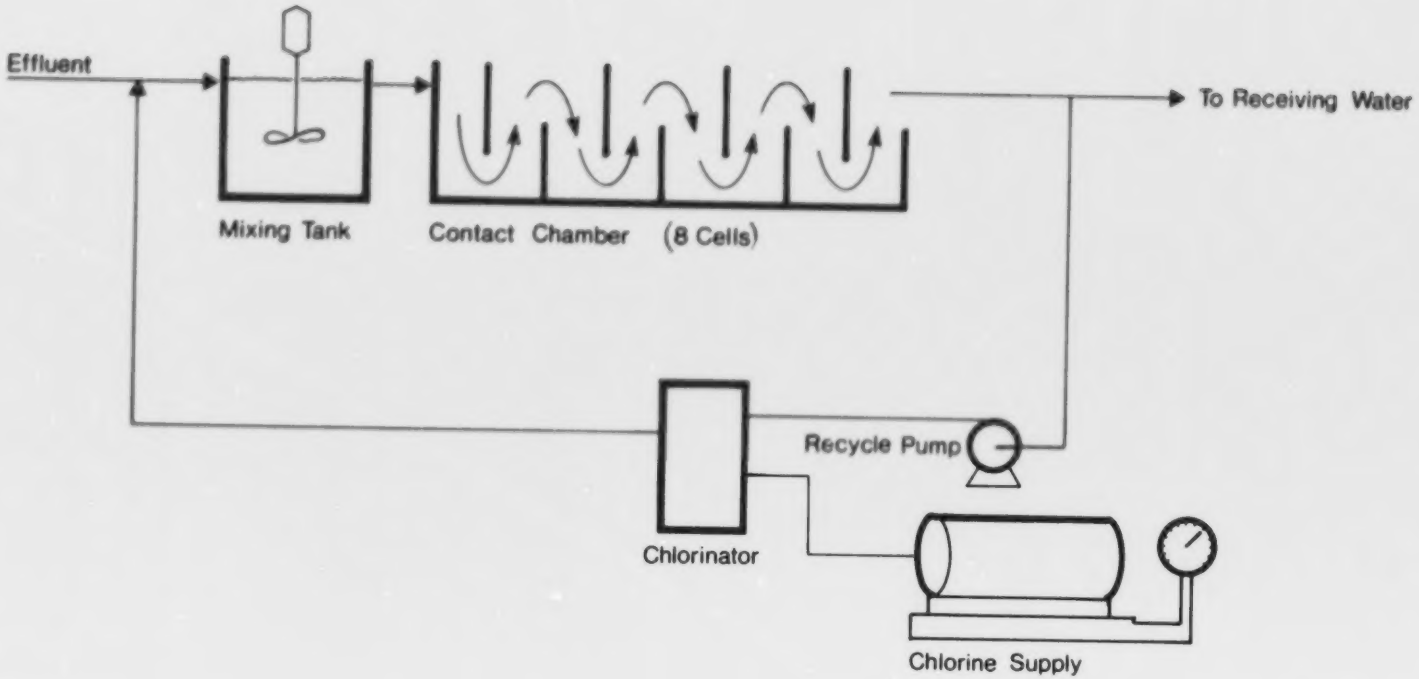


FIGURE 2 SCHEMATIC OF CHLORINATION SYSTEM FOR LAGOON EFFLUENT OR WEAK SEWAGE

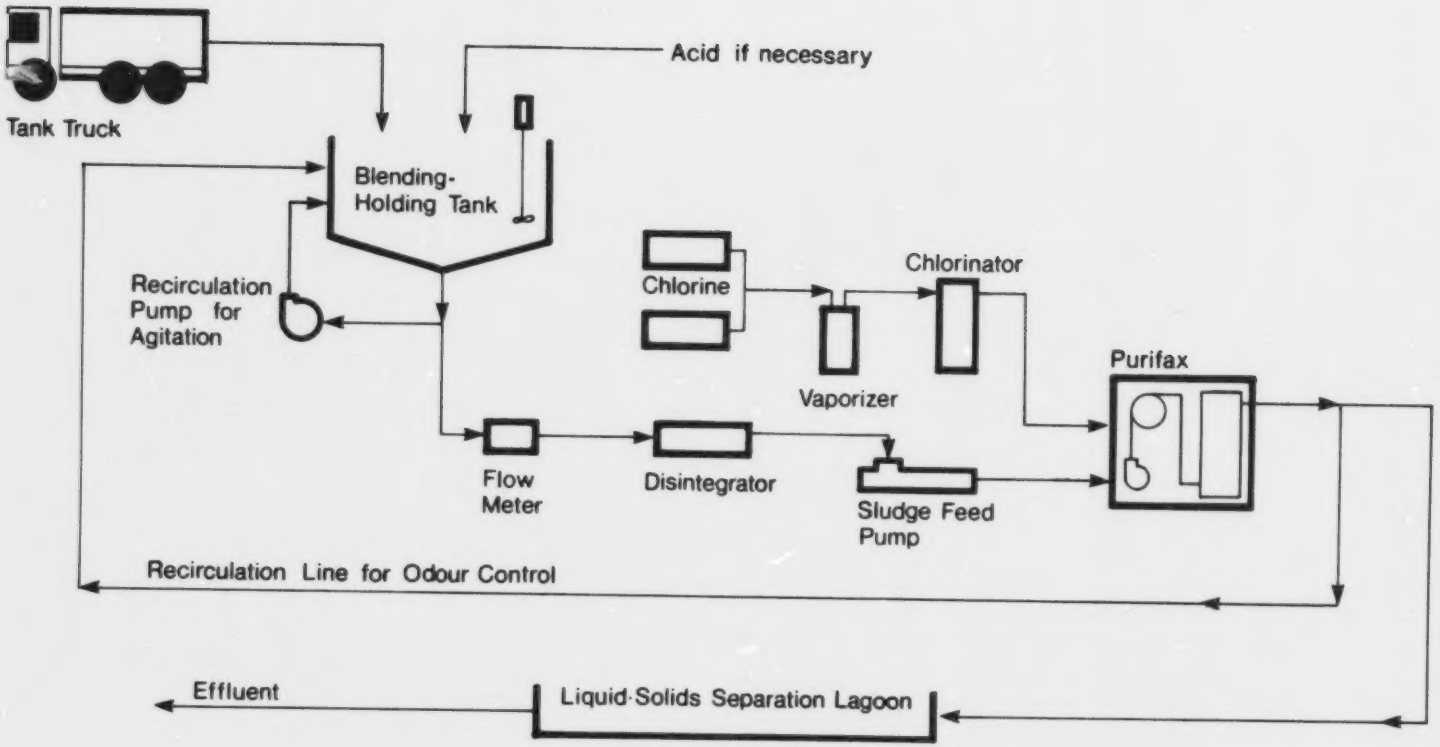


FIGURE 3 SCHEMATIC OF CHLORINATION (PURIFAX) SYSTEM FOR HONEY-BAG AND HOLDING TANK WASTES

TABLE 5a CHLORINATION DESIGN SUMMARY

	Lagoon Effluent	Weak Sewage
Average Flow (m^3/d)	1 360	3 180
Cl_2 Dosage (mg/L)	5	7
Cl_2 Residual (mg/L)	1.0	1.0
Contact Time (minutes)		
for $y/y_o = 5 \times 10^{-4}$	104	104
5×10^{-3}	35	35
5×10^{-2}	11	11
5×10^{-1}	6	6
Volume of Contact Chamber (m^3)		
for $y/y_o = 5 \times 10^{-4}$	98.5	226
5×10^{-3}	33.1	76.1
5×10^{-2}	10.4	23.9
5×10^{-1}	5.7	13.0
Number of Cells in Contact Chamber	8	8
Chlorine Usage at Average Flow (kg/day)	6.7	22
Chlorinator Capacity (kg/day)	13	44

design purposes was assumed to be equivalent to that for primary sludge or 0.075 kg of chlorine per kg of BOD in the waste (either honey-bag or holding tank). Only one dosage and hence one level of disinfection could be considered for this purpose as design data for application as a disinfection process was not available. Chlorine usage would be of the order of 880 kg/yr for holding tank wastes and 890 kg/yr for honey-bag wastes.

Due to the very high alkalinity of the honey-bag wastes, an initial acidification step would be required to remove most of the alkalinity prior to chlorination in the Purifax system so that carbon dioxide foaming could be avoided. This problem apparently would not occur for the more diluted holding tank wastes. Because of the high alkalinity of both the honey-bag and holding tank wastes, neutralization of the Purifax effluent would not be required, assuming that the initial acidification of the wastes left sufficient alkalinity to neutralize the acid produced in the chlorination process.

TABLE 5b CHLORINATION-DECHLORINATION DESIGN SUMMARY

	Lagoon Effluent	Weak Sewage
Chlorination Step		
Cl_2 Dosage (mg/L)	8	8
Cl_2 Usage at Average Flow (Kg/day)	10.9	10.9
Chlorination Capacity (Kg/day)	22.7	68.2
Cl_2 Residual (mg/L)	2.0	2.0
Contact Time (minutes)		
for $y/y_o = 5 \times 10^{-4}$	52	52
5×10^{-3}	18	18
5×10^{-2}	6	6
5×10^{-1}	3	3
Volume (m^3) of Contact Chamber		
for $y/y_o = 5 \times 10^{-4}$	49.2	115
5×10^{-3}	17.0	39.8
5×10^{-2}	5.7	13.3
5×10^{-1}	2.8	6.6
Number of Cells	8	8
Dechlorination Step		
Stoichiometric SO_2 dosage (mg/L)	1.8	1.8
Excess SO_2 (mg/L)	0.5	0.5
Total SO_2 dosage (mg/L)	2.3	2.3
SO_2 usage (kg/day)	3.2	7.3
Contact Time (minutes)	10	10

4.2 Gamma Irradiation

The effectiveness of gamma radiation from either cesium-137 or cobalt-60 sources to inactivate bacteria and viruses has been conclusively demonstrated in the literature. Work conducted by Murphy (1974) in conjunction with Vajdic (1974) on batch and continuous flow irradiation of secondary effluent from the Burlington Skyway treatment plant using a cobalt source forms the basis for the process designs presented in this report. The physical design of the irradiator was developed jointly by IEC Ltd. and Geodel Systems Inc.

The Burlington Skyway treatment plant is a conventional extended aeration plant treating sewage from a predominantly residential area. Batch irradiation studies on the final effluent in an AECL - Gammacell 220 were used to determine the rate of die-off of organisms with total radiation dosage.

The relationship illustrated in Figure 4 is defined by Equation (2):

$$y/y_o = 10^{-0.57R} \qquad (2)$$

where:
- y = total coliform concentration after irradiation,
- y_o = initial coliform concentration,
- y/y_o = survival ratio,
- R = absorbed radiation dosage in Rads x 10^{-4}.

Continuous flow studies on the pilot plant irradiator showed that the pilot scale system at Burlington required much higher radiation dosages to achieve the same bacterial kills as the batch system. Dry tracer studies and subsequent evaluation of the residence time distribution of the pilot system indicated that the less efficient performance was caused by short-circuiting the contact chambers.

Although Ontario Ministry of the Environment (MOE) studies have attempted to demonstrate improved settling and compaction of solids after radiation, there is not sufficient valid data to warrant any allowance in system design.

Based on the continuous flow of work at Burlington, IEC and Geodel designed a continuous flow system consisting of eight equal-sized mixed chambers in series which provided more uniform residence time distribution and resulted in much higher predicted efficiencies. A schematic of this system is shown in Figure 5.

The existing concentration ratio from a first order reaction occurring in a series of completely mixed tank continuous flow reactors is given by:

$$y/y_o = 1/(1 + k\,T_i)^n \qquad (3)$$

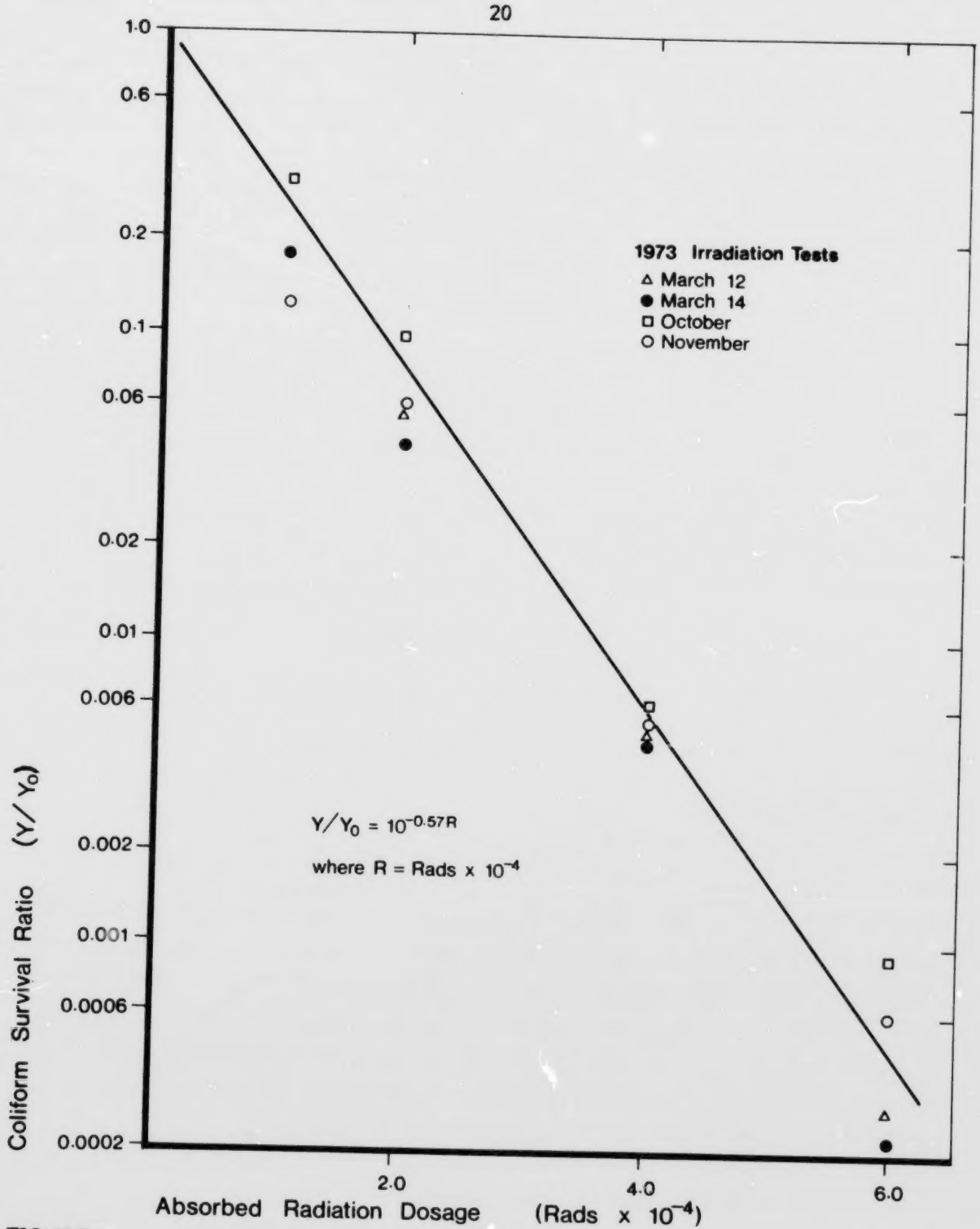
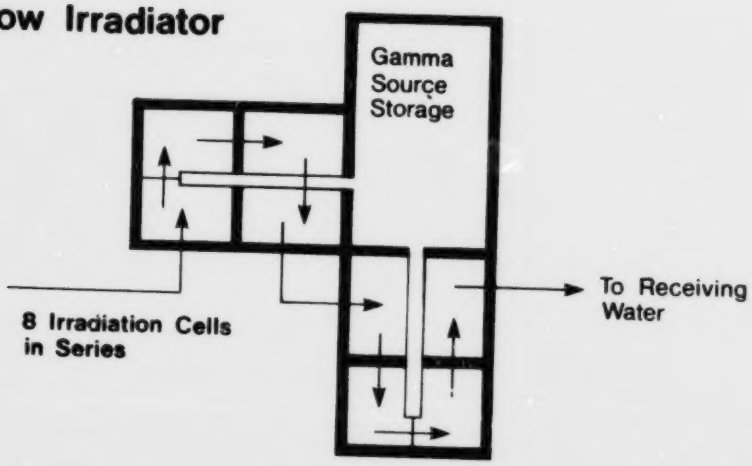


FIGURE 4 COLIFORMS SURVIVING IRRADIATION - GAMMACELL 220

a. Continuous Flow Irradiator



b. Batch Irradiator

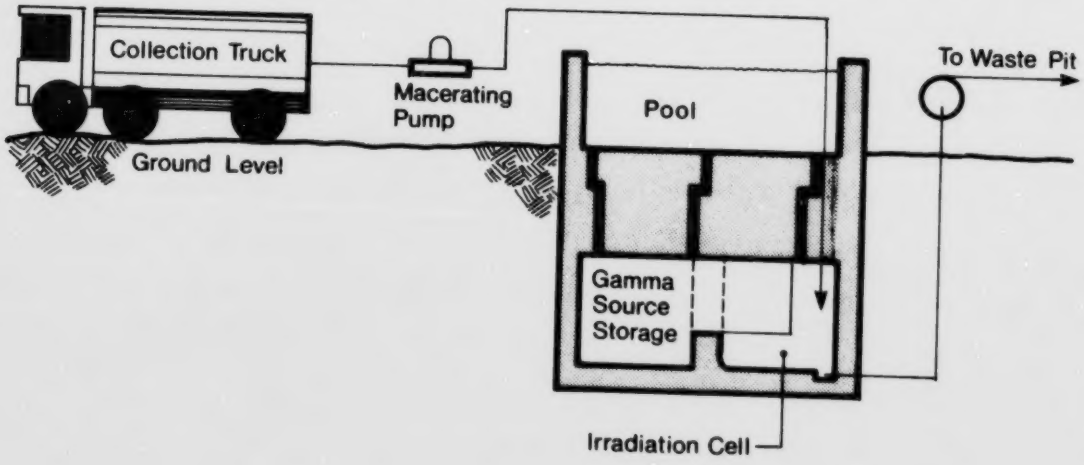


FIGURE 5 SCHEMATIC OF GAMMA IRRADIATION SYSTEMS

where: y = final concentration,
y_o = initial concentration,
k = reaction rate constant,
T_i = residence time of each tank,
n = number of tanks.

For eight tanks in series the equation becomes:

$$y/y_o = 1/(1 + k\,T_i)^8 \quad (4)$$

Substituting T_t/n for T_i (where T_t = total residence time) the equation becomes:

$$(y/y_o)^{1/8} = 1 + k\,T_t/8 \quad (5)$$

For the disinfection process y/y_o is the survival ratio, which allows the calculation of $k\,T_t$. For a first order reaction, the rate of reaction is defined as $y/y_o = 10^{-kt}$, and kt may be determined graphically from a graph of log y/y_o against reaction time t. For a given radiation source, the radiation dosage (R) is a function of exposure time T, which is equivalent to reaction time t for an irradiator. As the exposure time T is equal to the residence time T_t in an irradiator, the value 0.57R determined from Figure 4 may be equated to kT_t for the disinfection process, that is: $kt = kT = kT_t = 0.57R$. As $k\,T_t = 0.57R$, it is then possible to calculate the radiation dosage in rads irrespective of source material to achieve the desired survival ratio y/y_o.

$$R = k\,T_t/0.57 \quad (6)$$

Based on data provided by AECL, an 187 curie source emits radiation that would deliver 1×10^6 rads to 1 kg of material in one hour. The size of the radiation source then can be determined for an irradiator of given efficiency.

$$\text{Source (curies)} = \frac{r(\text{rads}) \times \text{Flow (L/d)} \times 187 \text{ curies}}{24 \times 10^6 \text{ (rad.kg/day)} \times \varepsilon} \quad (7)$$

where ε is the efficiency of irradiation in the type of irradiator.

For an irradiator similar to the eight cell unit designed for Geodel, an efficiency of 0.55 was calculated. The absorbed radiation dosages and source sizes required for each level of disinfection for each effluent or waste are shown in Table 6.

TABLE 6 SUMMARY OF PROCESS DESIGN PARAMETERS FOR DISINFECTION BY GAMMA IRRADIATION

	Flow m^3/d	Coliform Surviving Ratio	Process	Absorbed Dosage K Rads	Source Megacuries*
Lagoon Effluent	1 360	$5x10^{-4}$	8 comp. cont.	223	4.3
		$5x10^{-3}$	"	132	2.6
		$5x10^{-2}$	"	64	1.2
		$5x10^{-1}$	"	12.7	0.25
Weak Sewage	3 180	$5x10^{-4}$	8 comp. cont.	223	9.9
		$5x10^{-3}$	"	132	5.9
		$5x10^{-2}$	"	64	2.8
		$5x10^{-1}$	"	12.7	0.56
Honey-Bags	0.9	$9x10^{-8}$	Batch	123	$1.6x10^{-3}$
		$9x10^{-7}$	"	106	$1.4x10^{-3}$
		$9x10^{-6}$	"	88	$1.1x10^{-3}$
		$9x10^{-5}$	"	70	$0.9x10^{-3}$
Holding Tanks	45.9	$5x10^{-7}$	Batch	108	$60x10^{-3}$
		$5x10^{-6}$	"	91	$48x10^{-3}$
		$5x10^{-5}$	"	73	$37x10^{-3}$
		$5x10^{-4}$	"	56	$24x10^{-3}$

* Assumes 55% efficiency.

4.3 Ultraviolet Irradiation

Ultraviolet irradiation is used as a disinfection process for potable water systems in cruise ships and restaurants and for disinfection of high quality water supplies in industrial applications such as breweries and pharmaceutical manufacturing. The use of ultraviolet radiation in disinfection of waste water has not been studied extensively, although its feasibility has been demonstrated at a 1820 m^3/d pilot plant in the United States (U.S. EPA, 1976). The reliability was highly dependent on effluent quality and additional research was recommended to optimize UV dosage, hydraulics, contact time, energy requirements and minimum pre-treatment standards. Tertiary treatment by filtration may be required to achieve consistent disinfection. A 9100 m^3/d plant being

constructed near Rochester, New York will utilize filtration as tertiary treatment prior to UV disinfection.

In bench scale studies on effluents from the Burlington, Oakville and Hamilton sewage treatment plants, Oliver and Cosgrove (1975) showed that UV disinfection of effluents from activated sludge treatment plants was feasible to some extent, provided the effluent was low in suspended solids (9 to 21 mg/L) and colour. It is evident from their data that the disinfection efficiency begins to fall off significantly at survival ratios ranging from 10^{-2} to 10^{-3} for secondary effluents and at survival rations of 10^{-1} to 10^{-2} for raw sewage containing 150 mg/L suspended solids. This was attributed to shielding of bacteria the particulate matter.

Owing to the variability of the suspended solids concentration and total coliform counts found in the lagoon effluent and the weak sewage (Table 3), the feasibility of achieving consistent disinfection of these effluents with UV radiation alone is marginal.

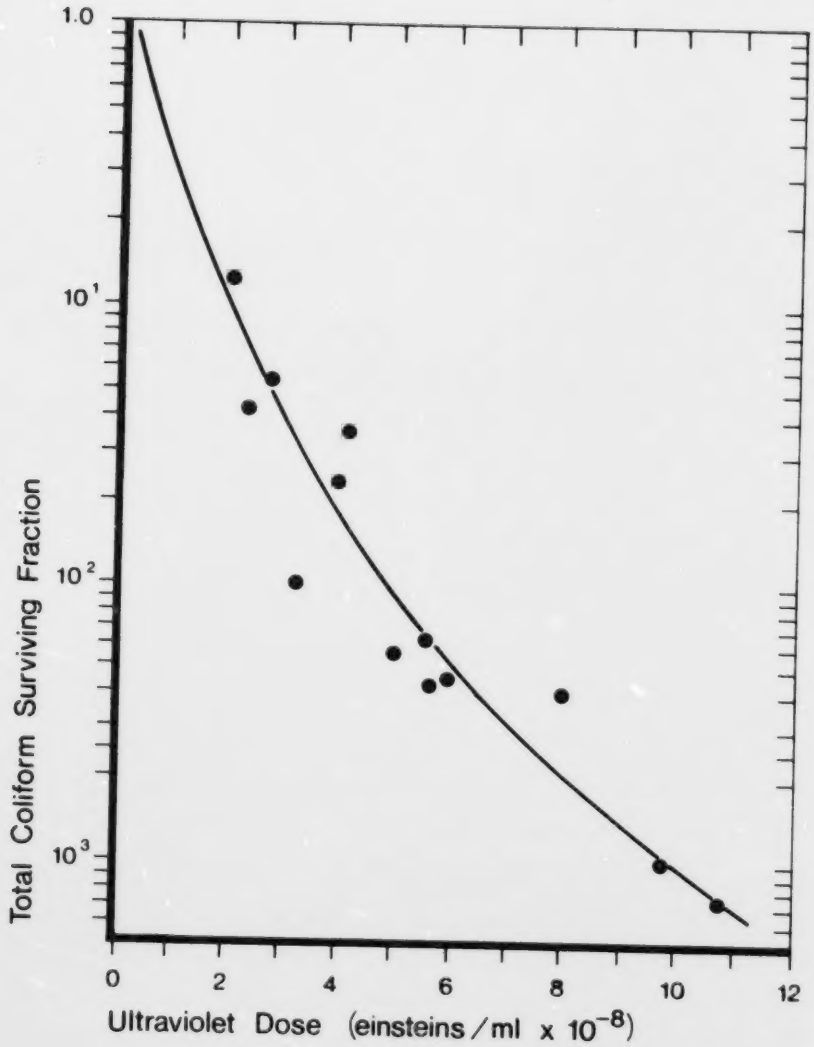
Based on the total coliform counts, and median suspended solids levels in the lagoon effluent and weak sewage (Oliver and Cosgrove, 1975), it is probable that UV irradiation alone will be able to achieve the bacterial kills required to reach the 50000 ($y/y_o = 5x10^{-1}$) level. It may also be possible with UV irradiation to reach the 5000 ($y/y_o = 5x10^{-2}$) and 500 ($y/y_o = 5x10^{-3}$) total coliform per 100 mL levels with low effluent suspended solids concentration, but not the 50 coliform per 100 mL level.

Design for UV disinfection facilities for lagoon effluent and weak sewage were based on the system described by Oliver and Carey (1975) which utilized UV irradiation of wastewater passing over a weir. Construction of weirs would be required with a maximum depth of flow over the weir of 1.5 cm. Ultraviolet irradiation dosages were estimated from data reported by Oliver and Carey (1975) shown in Figure 6. However, the number of lamps required was based on the use of high-intensity lamps with reflecting fixtures, unlike the system of Oliver and Carey, which utilized low-intensity lamps and open fixtures. The design parameters are summarized in Table 7, and the process schematic is shown in Figure 7.

Because of the very high suspended solids concentrations in honey-bag and holding tank wastes, UV disinfection is technically impracticable for these wastes.

4.4 Ozonation

Ozonation has been used extensively for disinfection of potable water supplies in Europe, particularly France. In Canada, it is employed principally in Quebec. Recently, research into the application of ozone as a wastewater disinfectant has been



(Oliver & Carey, 1975)

FIGURE 6 COLIFORM SURVIVAL RATIO AS A FUNCTION OF UV DOSAGE

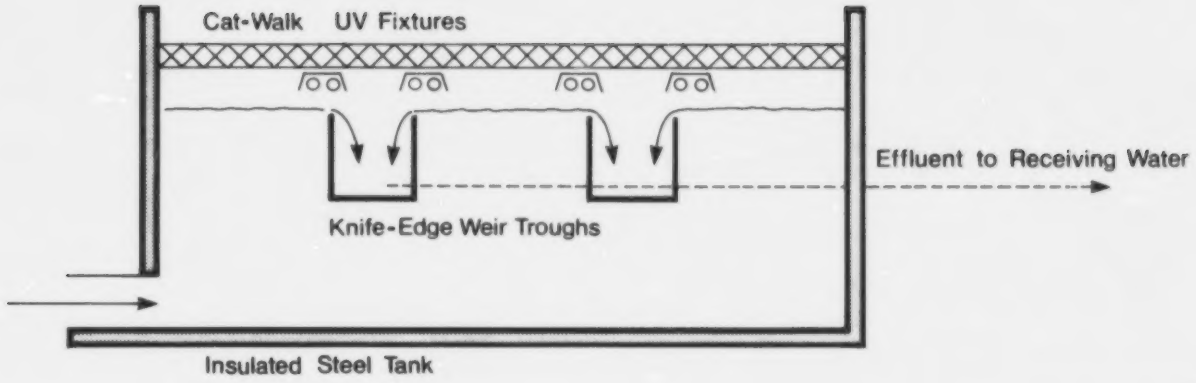


FIGURE 7 SCHEMATIC OF UV IRRADIATION SYSTEM

undertaken owing to concern over both the environmental effects and the availability of chlorine for wastewater disinfection. Diaper (1972) has demonstrated in full-scale plants that ozonation of secondary effluents preceded by microstaining achieves levels of bacterial kill adequate to meet most regulatory requirements at applied ozone dosages of 5 to 10 mg/L. Nebel et al (1973) have shown in batch studies that similar levels of ozone applied to secondary effluents will meet regulatory requirements. In both cases, effluent BOD and suspended solids were less than 10 mg/L.

In contrast, Kinman (1974) found that disinfection of a secondary effluent from a pilot plant treating a high percentage of industrial waste required dosages of 50 to 60 mg/L of ozone to achieve acceptable kill of organisms (i.e. survival ratios of $<10^{-4}$). In addition, Diaper (1972) stated that up to 25 to 40 mg/L of applied ozone may be necessary to oxidize organic material and to achieve adequate disinfection if a high level suspended solids removal is not practised.

Low-temperature studies by Smith and Given (1977) on ozone disinfection of weak sewage and effluent from a pilot scale Rotating Biological Contactor (RBC)

TABLE 7 SUMMARY OF PROCESS DESIGN PARAMETERS FOR DISINFECTION BY ULTRAVIOLET IRRADIATION

		Lagoon Effluent	Weak Sewage
Average Flow (m^3/d)		1 360	3 180
UV Dosage (einsteins/mL)			
for y/y_o =	5×10^{-1}	1.5×10^{-8}	1.5×10^{-8}
	5×10^{-2}	2.5×10^{-8}	2.5×10^{-8}
	5×10^{-3}	6.5×10^{-8}	6.5×10^{-8}
UV Power (watts)			
for y/y_o =	5×10^{-1}	105	240
	5×10^{-2}	185	425
	5×10^{-3}	480	1 105
No. of Fixtures*			
for y/y_o =	5×10^{-1}	6	13
	5×10^{-2}	10	23
	5×10^{-3}	26	60
Length of Weir (m)			
for y/y_o =	5×10^{-1}	6.1	12.2
	5×10^{-2}	9.1	21.3
	5×10^{-3}	24.4	58.9

* Assumes 2-lamp fixtures at 29.6 UV watts per fixture at 63% efficiency and 1500 watts = 3.2×10^{-3} einsteins/sec; 86 watts power per metre-long fixture.

secondary treatment system showed that substantially greater ozone dosages are required for the disinfection of the weak sewage (BOD 90 mg/L; suspended solids 100 mg/L) as compared to the RBC effluent (BOD <7 mg/L; suspended solids <5 mg/L). The data of Smith and Given (1977) and of Nebel et al (1973) are presented in Figure 8. Survival ratio (y/y_o) has been plotted as a function of $1 + C_A$ where C_A is the applied ozone dosage. The method of graphical presentation was adapted from the work of Sellick et al (1970) on chlorination.

As shown in Figure 8, the line through the data for weak sewage has a significant intercept on the $1 + C_A$ axis. This "threshold level" is caused by the initial

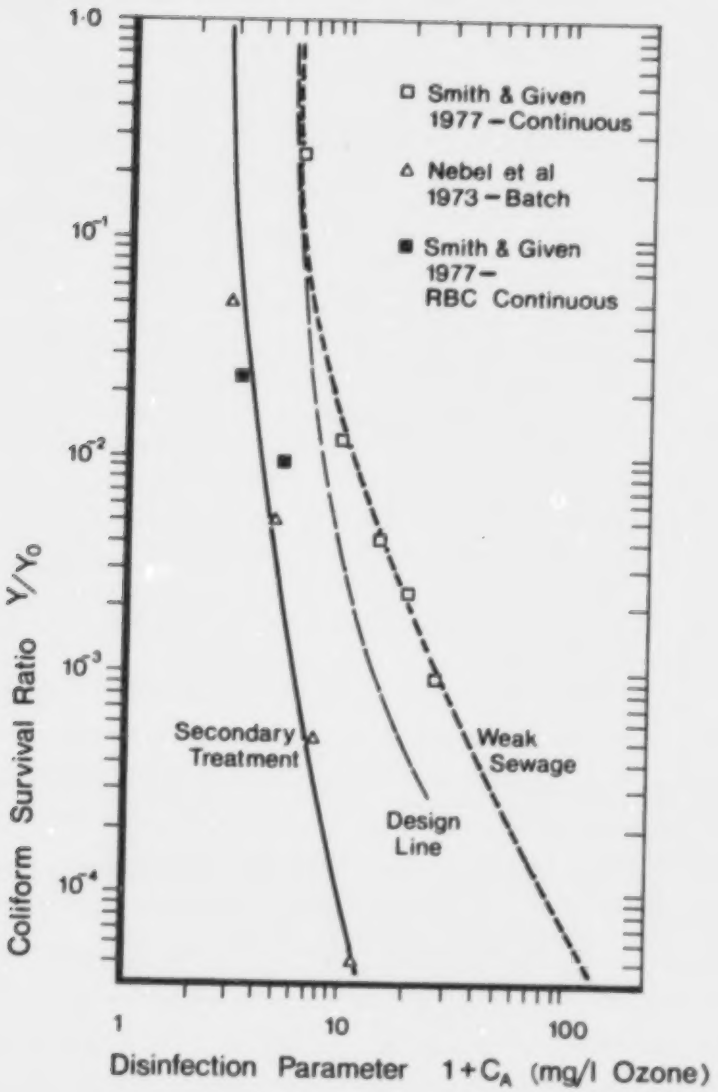


FIGURE 8 COLIFORM SURVIVAL AT VARIOUS OZONE DOSAGES

ozone demand of the BOD and suspended solids in the waste of approximately 5.0 mg/L. Diaper (1972) reported a threshold of approximately 3.0 mg/L for microstrained secondary effluents. A similar threshold level is expected for the RBC effluent data of Smith and Given (1977) and the data of Nebel et al (1973).

The ozone design dosages for lagoon effluent and weak sewage were estimated to be higher than those required for the RBC effluent. This was because the BOD and suspended solids levels of these effluents were higher than those of the RBC effluent. The design parameters for these wastewaters (Figure 8) are summarized in Table 8. The system is schematically illustrated in Figure 9. For a survival ratio of 5×10^{-1} the threshold level of 5.0 mg/L has been used as the design dosage. A contact time of 10 minutes, five minutes contact per column, has been selected in accordance with current practice for disinfection by ozonation. A Canadian ozone equipment supplier recommends eight minutes total contact time, while Diaper (1972) stated that two columns with five minutes contact each have been used successfully in the Hanover Park studies in Chicago.

TABLE 8 SUMMARY OF PROCESS DESIGN PARAMETERS FOR DISINFECTION BY OZONATION

	Flow (m^3/d)	Survival Ratio	Applied Ozone Dosage (mg/L)	Ozone Application Rate (kg/d)	Contact Time* (minutes)
Lagoon	1 360	5×10^{-1}	5.0	6.7	10
Effluent		5×10^{-2}	5.0	6.7	10
		5×10^{-3}	8.0	11	10
		5×10^{-4}	17.0	23	10
Weak	3 180	5×10^{-1}	5.0	16	10
Sewage		5×10^{-2}	5.0	16	10
		5×10^{-3}	8.0	25	10
		5×10^{-4}	17.0	53	10

* 5 minutes per contact column

Because of the extremely high BOD and suspended solids concentration and their resultant ozone demand, ozonation is not regarded as a technically feasible disinfection alternative for holding tank and honey-bag wastes.

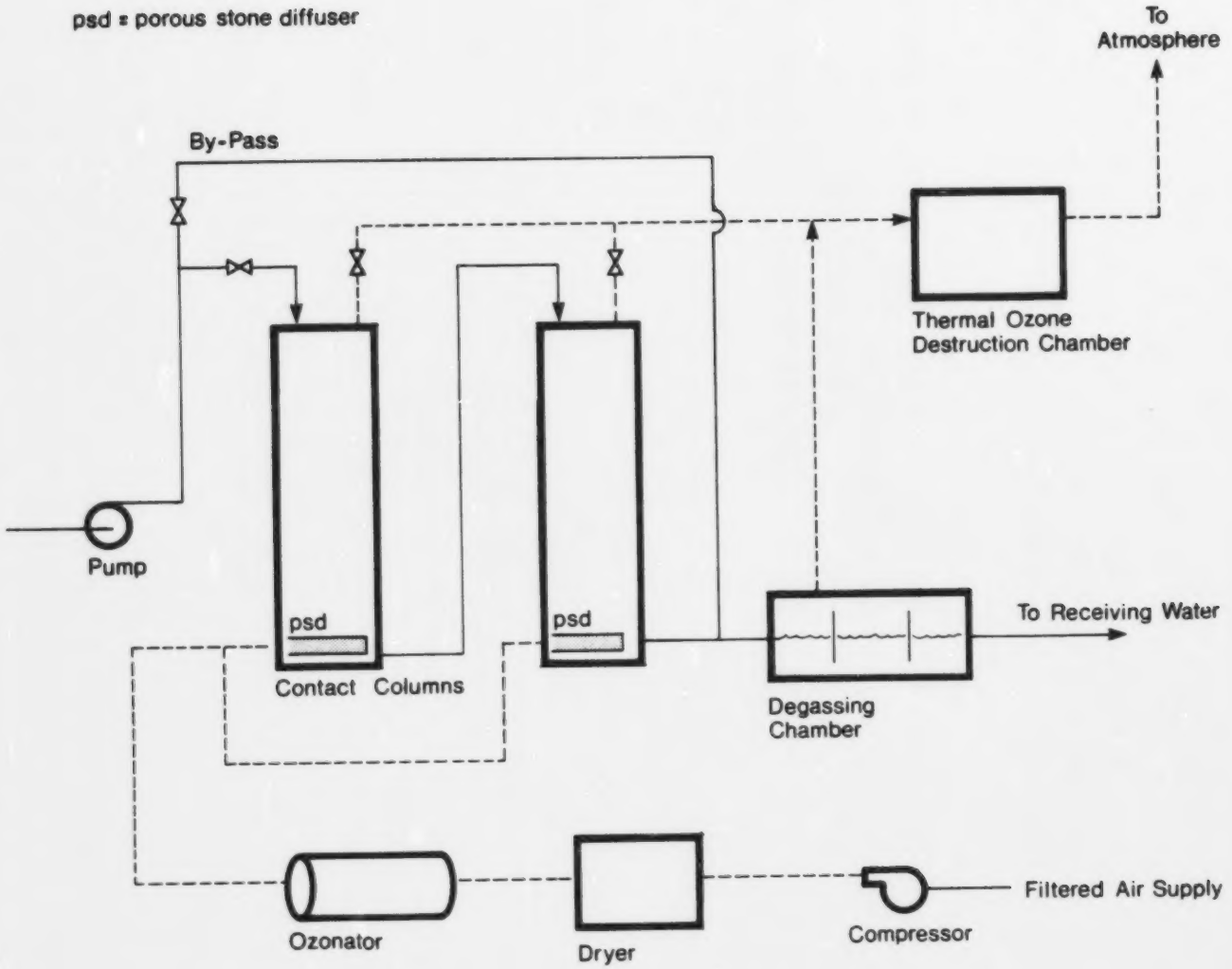


FIGURE 9 SCHEMATIC OF OZONATION SYSTEM

4.5 Lime Disinfection

The bactericidal properties of hydroxides applied to achieve evaluated pH levels in raw water and domestic wastewater have been well documented. Morrison and Martin (1974) reviewed the history of disinfection by high pH as background to their own research on lime disinfection in domestic wastewater at low temperatures. Working with raw sewage and secondary effluent, they showed that a pH of 11.0 or greater is required to achieve 1000 total coliforms per 100 mL from initial counts of about 10^6 total coliforms per 100 mL in less than 12 to 24 hours at 1°C. Detention times of this length are impractical for application to systems discharging large volumes of weak sewage or lagoon effluent such as at Dawson or Inuvik. However, they are feasible in batch systems such as would be utilized for honey-bag wastes.

Increasing the pH to about 11.5 reduced the detention time required from two to three hours for the disinfection levels above. Such detention times are feasible for lagoon effluent and weak sewage, although the handling and disposal of lime sludge becomes a problem with the lime dosages required to achieve these high pH levels. Sludge recycle reduces the problem. In addition, pH reduction in the effluent is required prior to discharge to the receiving water.

Figure 10 shows the relationship between the survival ratio y/y_o and the product of hydrogen ion concentration and detention time as calculated from the secondary effluent data of Morrison and Martin (1974) at 1°C. The slopes of the lines change as the pH is increased from 11.0 to 12.0.

Figure 11 illustrates that the lime dosages required to achieve pH values greater than 11.5 increase substantially. The designs evaluated in this study are based on use of values in the range 11.0 to 11.5 to reduce chemical costs and lime sludge handling problems. Table 9 summarizes the design values for the parameters selected, based on the work of Morrison and Martin (1974). The assumption is made that the weak sewage is essentially the same as the lagoon effluent in its response to elevated pH levels. A schematic of the process is shown in Figure 12. The system consists of a flash mix tank to contact the fresh and recycled lime with the wastewater followed by a reactor clarifier. Lime sludge recycle can account for up to 25 percent of the daily lime requirements in such a system. Where receiving water flows are too low to allow dilution of the high pH effluent, neutralization of excess lime must be provided.

As there is little previous experience or data on lime disinfection of honey-bag and holding tank wastes, the lime dosages were estimated from the lime demand of the

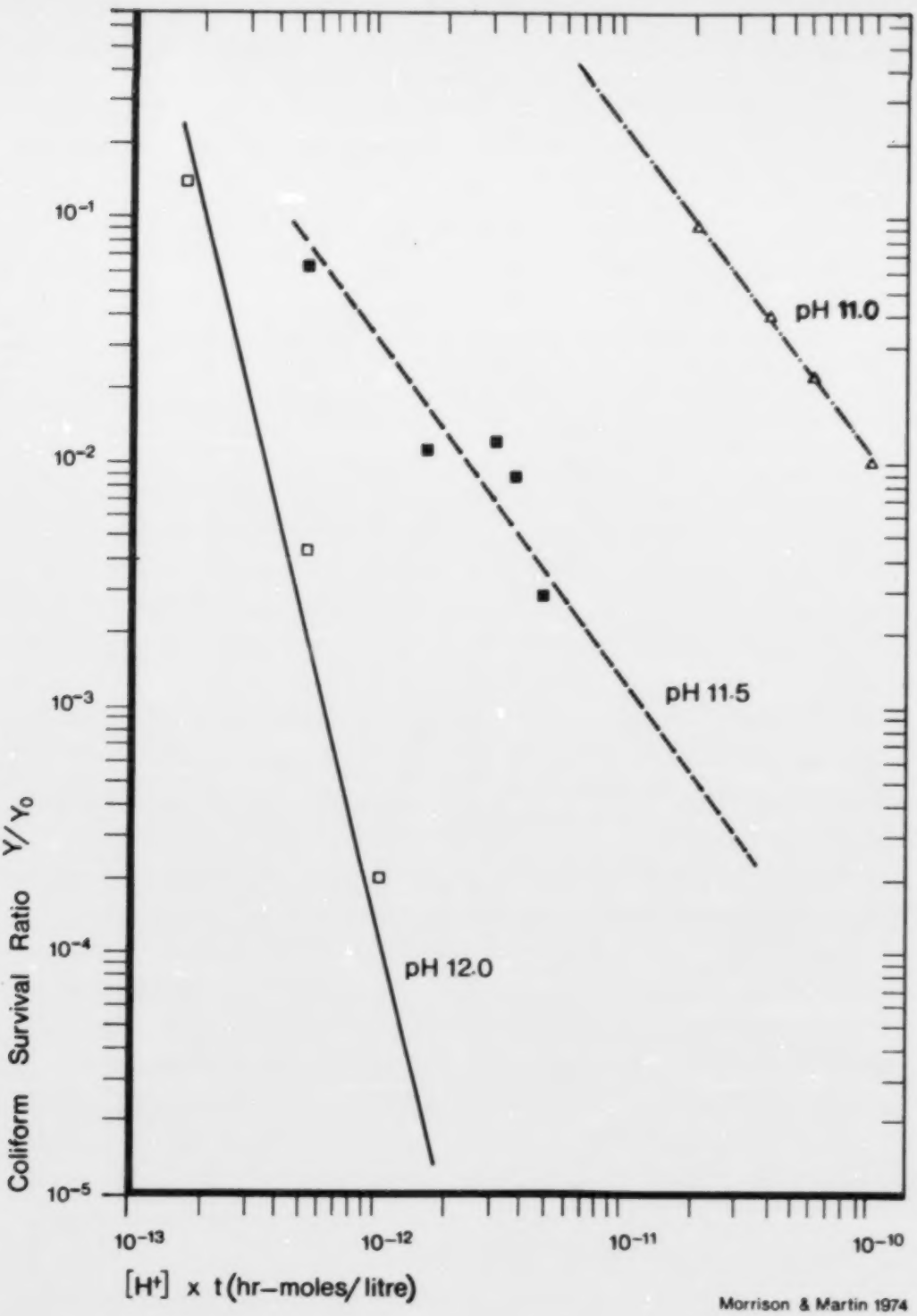
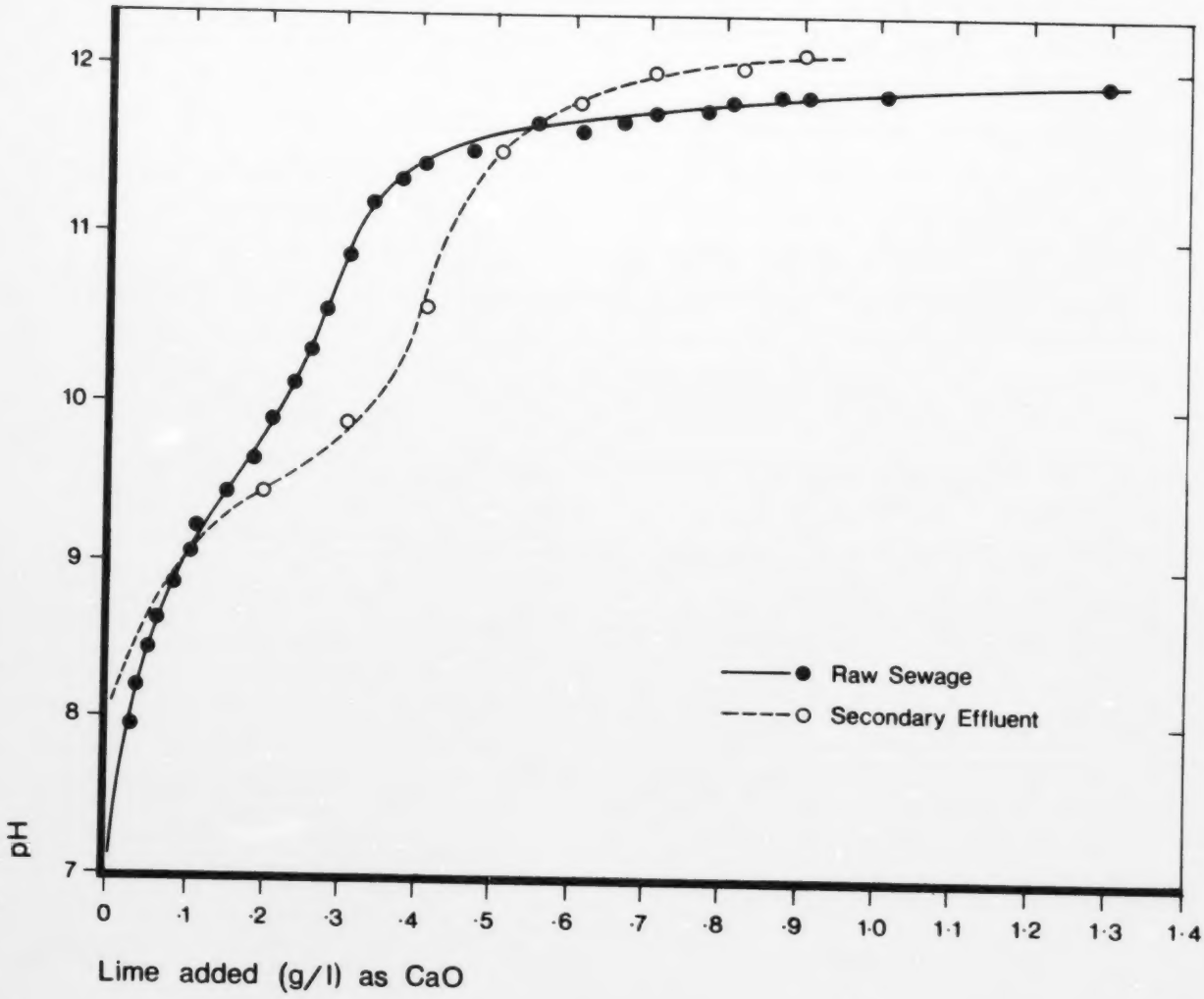


FIGURE 10 COLIFORM SURVIVAL AT VARIOUS HYDROGEN ION CONCENTRATIONS



(Adapted from Morrison & Martin,1974)

FIGURE 11 pH AS A FUNCTION OF LIME DOSAGE

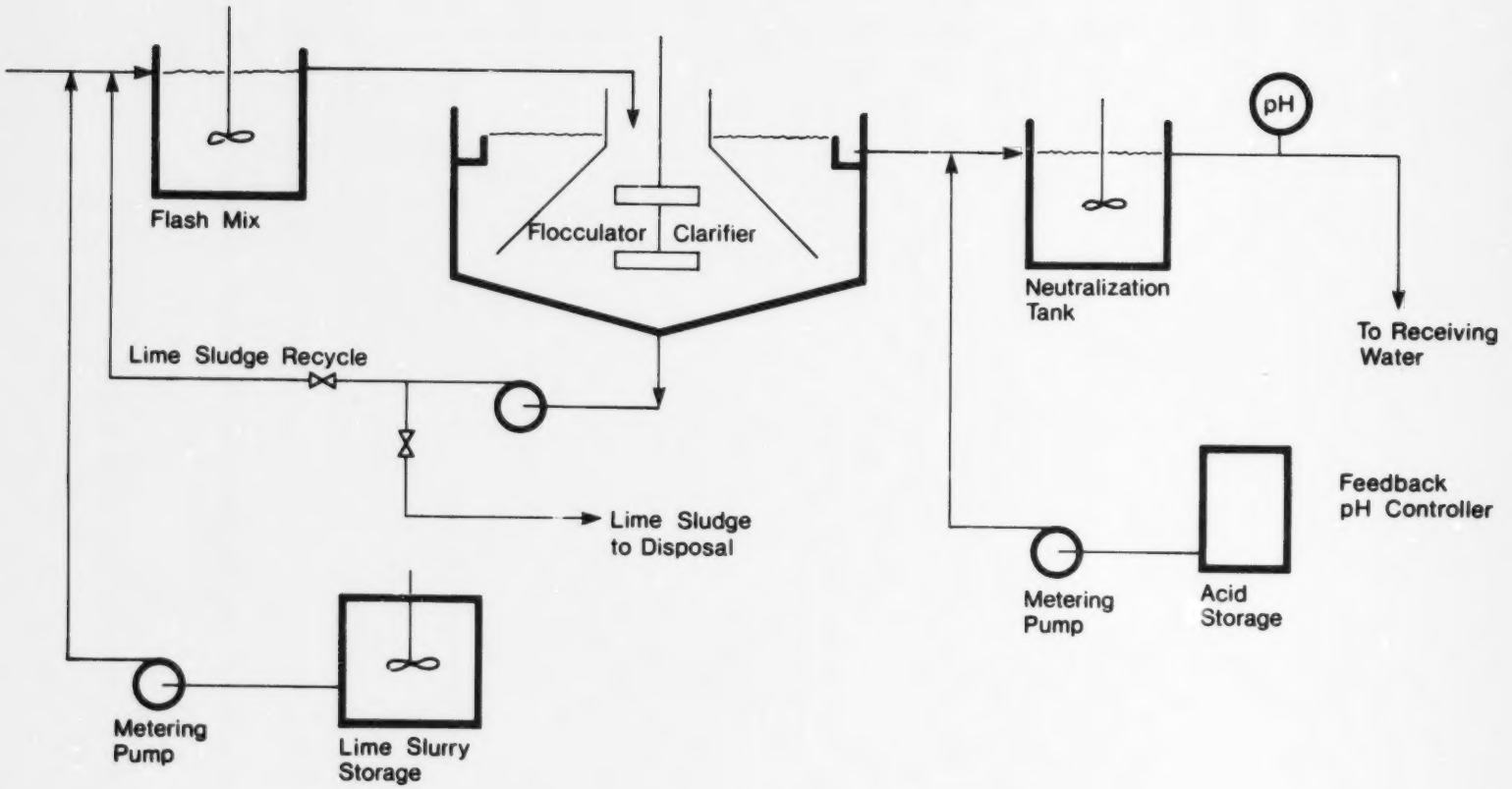


FIGURE 12 SCHEMATIC OF LIME DISINFECTION PROCESS FOR LAGOON EFFLUENT AND WEAK SEWAGE AT INUVIK AND DAWSON

alkalinity and the lime requirement for attaining a pH of 11.5 to 12 in low alkalinity water as described by Morrison and Martin (1974 - see Figure 11). The lime dosage and usage figures are presented in Table 9.

The system shown schematically in Figure 13 for the disinfection of honey-bag wastes assumes that these wastes would be collected in a truck equipped with a "ripper chute" which permits separation of the bag and its contents. A macerating plump would be used to empty the truck tank, and reduce the size of the suspended solids prior to treatment. The waste would be treated on a one batch per day basis, with a six-hour cycle time from emptying of the tank truck to final discharge of the limed effluent to the sludge pit.

Because of the small lime requirement bagged lime would be added manually to the system. Due to the relatively long detention time in the treatment tank, a pH of approximately 11.5 should be adequate to provide almost complete disinfection. As there are no data available on the pH dependence of disinfection of honey-bag wastes a single dosage has been assumed. Neutralization of the limed waste would not likely be necessary as the entire volume would be disposed of to a waste (sludge) pit and little decant to the environment would be expected.

The lime disinfection of holding tank wastes would be achieved by the semi-continuous process illustrated in Figure 14. It has been assumed that collection and processing of the holding tank wastes would be accomplished during one eight hour shift per day, five days per week. Storage capacity for about two-thirds of the daily volume has been provided in two equalization tanks. Disinfection would occur in the flocculator-clarifier, operated at a constant throughput during the eight hour shift. A pH of approximately 12 would probably be required to achieve adequate disinfection with the two hour detention time in the reactor clarifier. As shown in the summary of disinfection process parameters in Table 9, only one pH level has been considered. There is insufficient data on the treatment of holding tank wastes to determine what pH levels and lime dosages would be required to achieve levels of disinfection. The design as presented provides adequate information to assess the approximate cost of treatment.

TABLE 9 SUMMARY OF DESIGN PARAMETERS FOR LIME DISINFECTION

	Flow (m^3/d)	Survival Ratio	Detention Time (h)	pH Required	Lime Dosage (mg/L)	Lime Usage* (kg/d)
Lagoon	1360	5×10^{-1}	2.25	10.5	520	520
Effluent		5×10^{-2}	2.25	11.1	590	590
		5×10^{-3}	2.25	11.4	660	660
		5×10^{-4}	2.25	11.7	730	730
Weak Sewage	3180	5×10^{-1}	3.4	10.5	520	1200
		5×10^{-2}	3.4	11.0	560	1300
		5×10^{-3}	3.4	11.4	660	1540
		5×10^{-4}	3.4	11.6	730	1700
Holding Tank	45.9	-	2.0	12	2000	125
Honey-Bag	0.9	-	4.0	11.6	12000	10

* Note: Assumes 25% recycle

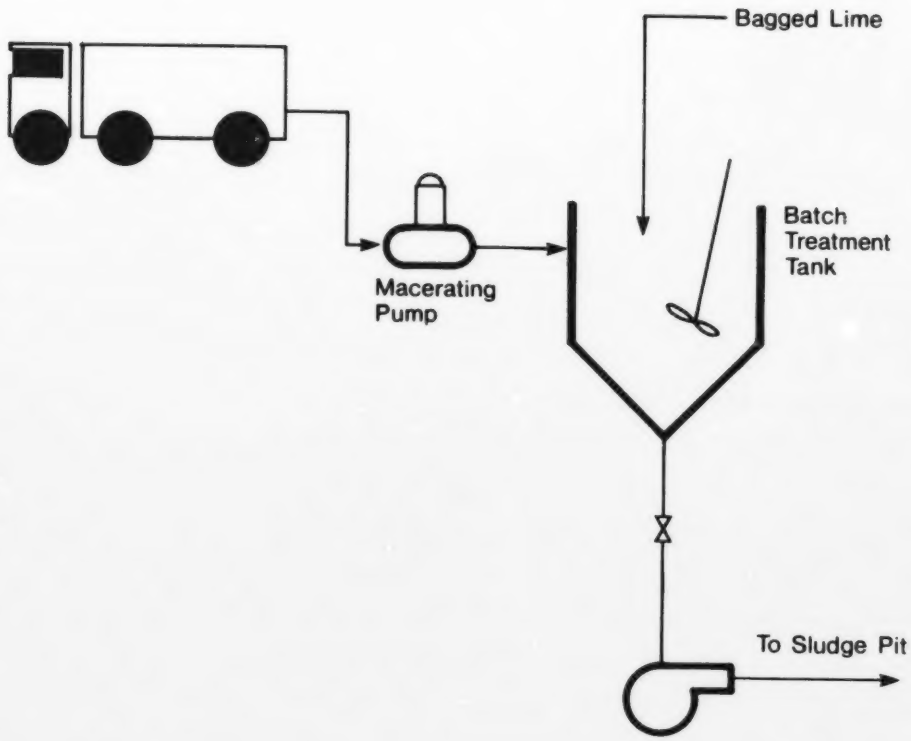


FIGURE 13 SCHEMATIC OF LIME DISINFECTION SYSTEM FOR HONEY-BAG WASTES

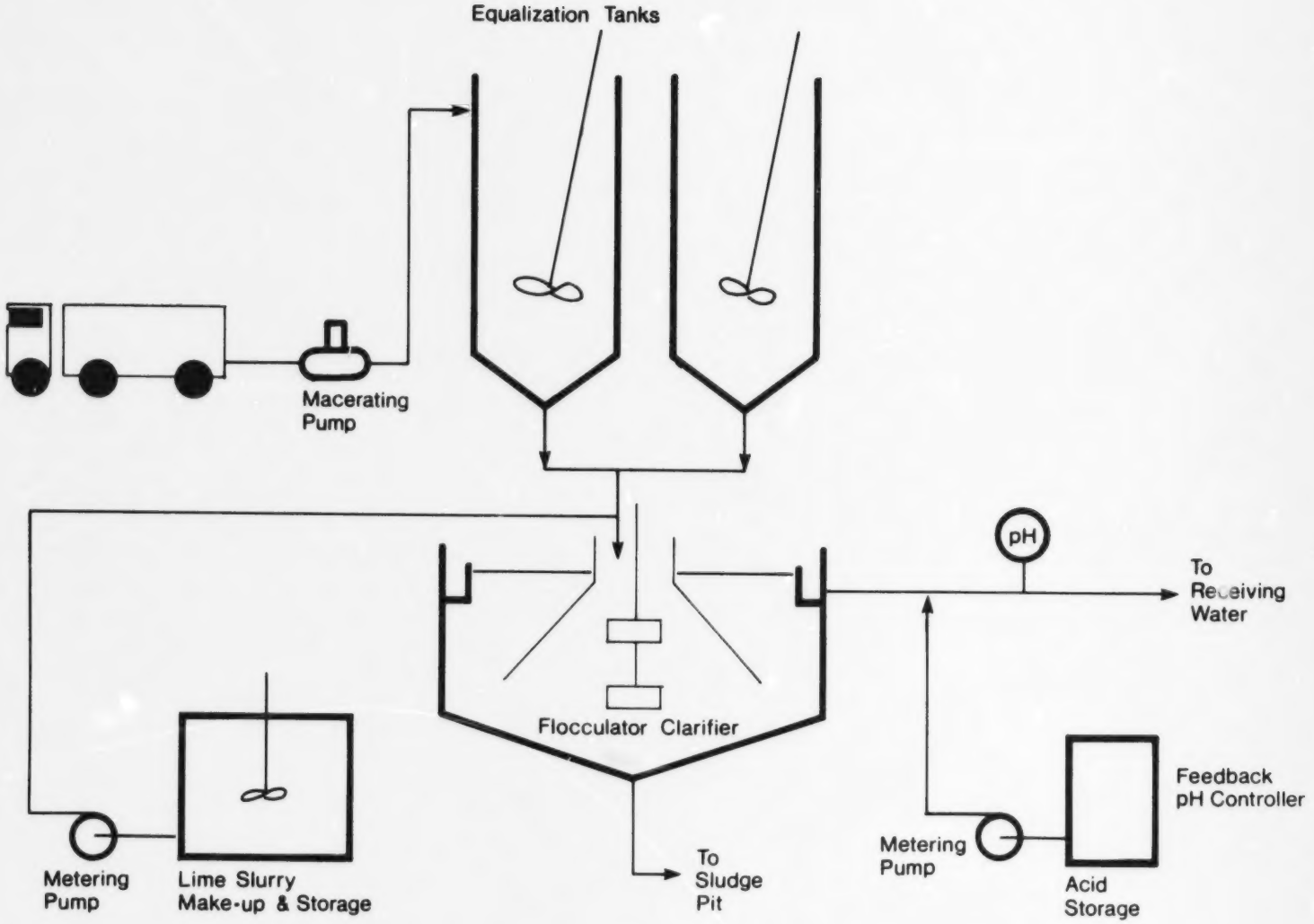


FIGURE 14 SCHEMATIC OF LIME DISINFECTION FOR HOLDING TANK WASTES

5 COST ESTIMATES FOR DISINFECTION

The purpose of estimating the costs of the various disinfection processes was to provide comparisons of the relative costs of the different process alternatives and to assess the costs of disinfection in the Arctic with respect to the equivalent installation in the south. It should be emphasized at that outset that the accuracy of the cost estimates is directly related to the reliability of the cost data used as a basis for the costing procedures. As effluent disinfection processes have not been installed in any northern community to date, costs of construction, installation, engineering and operation have been approximated from the best available data on similar or related projects such as water chlorination plants, pumping stations, water and oil storage tanks, and public buildings. Equipment costs were readily obtained from suppliers in the south, while operating costs were adjusted from similar southern installations to account for transportation costs, electricity costs, etc. Based on the detail provided for each process, the cost estimates should be treated as "level 2" or "study estimates" with an accuracy of ± 30 percent (Peters and Timmerhaus, 1969).

One of the major sources of costing information for this phase of the work was a recent Government of the Northwest Territories (NWT) publication entitled "Water and Sanitation Project Costs" (Armstrong et al. 1977), which summarized and reviewed historical cost information for most major water and sewer projects undertaken since 1970. More detailed information on specific projects was obtained from contractors' tender documents supplied by the NWT Department of Public Works.

This chapter describes the assumptions, data sources and methods used to arrive at capital and operating costs for the individual process alternatives. Capital costs were broken down into four categories - engineering, equipment, installation, and construction. Operating costs were detailed as to energy (both process requirements and heat and light), labour, chemicals (sub-categorized by purchase cost f.o.b. south and delivery cost) and maintenance. The costing of each process alternative is summarized in this chapter, while the estimated capital and operating costs for all levels of disinfection are detailed in Tables A-1 to A-16, Appendix 1.

5.1 Capital Costs

Based on the process designs presented in the previous chapter, cost estimates for disinfection process equipment for each system were obtained from a southern supplier f.o.b. Edmonton. Shipping weights of equipment were obtained as well, so that

the f.o.b. site equipment cost could be calculated using the freight rates tabulated in the NWT report, and reproduced in Table 10. No special crating or handling charges were included in the calculation of equipment cost f.o.b. site. The freight rate for Dawson, not included in the NWT report, was taken as $6.14/50 kg.

Capital costs for contact tanks for most systems were estimated based on all-steel construction, fully prefabricated by the supplier when small enough, or cut and marked for field erection. Field erection costs were considered to be installation costs. Mechanical and electrical appurtenances were included in the equipment costs, but installation of the appurtenances was considered to be an installation cost.

As indicated, installation costs included mechanical and electrical hookups and on-site erection of tanks. Southern installation costs, as estimated by the supplier, were increased so that the installation fraction of the total capital cost was equivalent to that for similar projects. For example, the proportion of the total capital cost required for installation of the chlorination and chlorination-dechlorination systems was assumed to be equivalent to that for installation of a package drinking water chlorination system. In general, this approach resulted in a doubling of the southern installation costs.

Construction costs included the costs of excavation, installation of concrete pads on ventilated gravel foundations, and the erection of a building to house the entire process system to prevent freeze-up in the winter. Building quality and costs per square metre were assumed to be equivalent to vehicle service garages in Yellowknife. Data for calculation of an average cost per square metre were taken from the NWT report (Armstrong et al, 1977). Construction costs were adjusted for location according to the cost factors calculated by the NWT Department of Public Works and verified by review of contractors' tender documents. These factors are presented in Table 11.

Based on the information presented in the NWT report for water chlorination systems and similar public utilities projects (Armstrong et al, 1977), as well as contract tender documents, engineering costs including site supervision ranged from 12 to 16 percent of the total project capital cost. For purposes of these estimates a constant 15 percent was assumed.

It should be noted that the estimates of capital costs do not include land purchase as this cost was assumed to be minimal. In addition, no allowance was made for the installation of electrical service lines to the disinfection process site, nor was any allowance made for garages or laboratories at the site. The capital costs do include costs for booster pumps for the process, but not pumping stations and pipelines for intake or

TABLE 10 FREIGHT RATES FOR NORTHERN COMMUNITIES

BAFFIN REGION*

Location	Northern Community Index	Vehicles $/50 kg	Construction Materials	
			Heavyweight $/50 kg	Lightweight $/50 kg
Arctic Bay	1.77	33.79	11.74	28.68
Broughton Island	1.75	34.84	12.08	29.46
Cape Dorset	1.63	24.47	8.69	21.02
Clyde River	1.75	33.85	12.08	29.46
Frobisher Bay	1.58	24.47	8.69	21.02
Grise Fiord	1.91	33.79	11.74	28.68
Hall Beach	1.76	32.59	11.34	27.70
Igloolik	1.76	32.59	11.34	27.70
Lake Harbour	1.62	24.47	8.69	21.02
Pangnirtung	1.70	24.47	8.69	21.02
Pond Inlet	1.71	33.79	11.74	28.68
Port Burwell	1.61	24.47	8.69	21.02
Resolute Bay	1.77	33.79	11.74	28.68
Sanikiluaq	1.65	27.83	9.77	21.02
Strathcona Sound	1.77	33.79	11.74	28.68

* F.O.B. Montreal rates do not include any special handling or crating charges and cost variations are anticipated during normal construction when some materials would inevitably be transported at higher or lower weight values and/or by other methods.

TABLE 10 FREIGHT RATES FOR NORTHERN COMMUNITIES (Cont'd)

INUVIK REGION*

Location	Northern Community Index	Vehicles $/50 kg	Construction Materials	
			Heavyweight $/50 kg	Lightweight $/50 kg
Aklavik	1.52	18.70	6.88	6.88
Arctic Red River	1.52	18.41	6.39	6.39
Coville Lake**	1.60	-		
Fort Franklin	1.55	20.62	8.16	8.16
Fort Good Hope	1.52	17.45	6.05	6.05
Fort McPherson	1.52	18.70	6.88	6.88
Fort Norman	1.50	16.64	5.51	5.51
Inuvik	1.47	18.70	6.88	6.88
Norman Wells	1.49	16.64	5.51	5.51
Paulatuk	1.75	23.97	10.40	10.40
Sachs Harbour	1.76	21.81	8.96	8.96
Tuktoyaktuk	1.58	19.44	7.38	7.38
Wrigley	1.44	16.36	5.32	5.32

* F.O.B. Edmonton rates do not include any special handling or crating charges and cost variations are anticipated during normal construction when some materials would inevitably be transported at higher or lower weight values and/or by other methods.

Freight charge from Edmonton to Hay River = 12.62/50 kg for vehicles,

= 2.75/50 kg for construction materials.

** A = via airfreight

From: Armstrong et al (1977)

TABLE 10 FREIGHT RATES FOR NORTHERN COMMUNITIES (Cont'd)

FORT SMITH REGION*

Location		Northern Community Index	Vehicles $/50 kg	Construction Materials Heavyweight $/50 kg	Construction Materials Lightweight $/50 kg
Bathurst Inlet		1.69	27.69	12.88	12.88
Cambridge Bay		1.69	26.38	12.00	12.00
Coppermine		1.70	25.08	11.14	11.14
Detah	H	1.35	14.74	4.18	4.18
Fort Liard		1.44	14.47	4.60	4.60
Fort Providence	H	1.38	13.44	3.30	3.30
Fort Resolution	H	1.38	13.79	3.54	3.54
Fort Simpson	H	1.38	14.11	3.75	3.75
Fort Smith	H	1.38	13.79	3.54	3.54
Gjoa Haven		1.79	28.65	13.51	13.51
Hay River	H	1.30	12.62	2.75	2.75
Holman Island		1.75	22.96	9.72	9.72
Kakisa Lake	H	1.38	13.44	3.30	3.30
Jean Marie River	H	1.43	14.21	3.85	3.85
Lac La Martre	A	1.46			
Nahanni Butte		1.44	14.77	4.90	4.90
Pelly Bay	A	1.76			
Pine Point	H	1.34	13.21	3.14	3.14
Rae/Edzo	H	1.39	14.69	4.14	4.14
Rae Lakes	H	1.46	14.72	4.17	4.17
Snowdrift		1.46	16.77	5.60	5.60
Spence Bay		1.80	29.47	14.06	14.06
Trout Lake	A	1.52			
Yellowknife		1.30	14.69	4.14	4.14

* F.O.B. Edmonton rates do not include any special handling or crating charges and cost variations are anticipated during normal construction when some material would inevitably be transported at higher or lower weight values and/or by other methods.

Freight charge from Edmonton to Hay River = 12.62/50kg for vehicles
= 2.75/50kg for construction materials

H = via highway system; A = via airfreight

TABLE 10 FREIGHT RATES FOR NORTHERN COMMUNITIES (Cont'd)

KEEWATIN REGION*

Location	Northern Community Index	Vehicles $/50 kg	Construction Materials	
			Heavyweight $/50 kg	Lightweight $/50 kg
Baker Lake	1.62	26.13	13.24	13.24
Chesterfield Inlet	1.65	26.13	13.24	13.24
Coral Harbour	1.66	26.13	13.24	13.24
Eskimo Point	1.59	26.13	13.24	13.24
Rankin Inlet	1.59	26.13	13.24	13.24
Repulse Bay X	1.70	32.59	14.58	27.70
Whale Cove	1.65	26.13	13.24	13.24

* F.O.B. Winnipeg rates do not include any special handling or crating charges and cost variations are anticipated during normal construction when some materials would inevitably be transported at higher or lower weight values and/or by other methods.

Freight charge from Winnipeg to Churchill = 15.81/50 kg for vehicles,
= 2.91/50 kg for construction materials.

X = Rates via F.O.B. Montreal

TABLE 11 CONSTRUCTION COST FACTORS FOR SERVICE GARAGES IN THE NORTHWEST TERRITORIES

Location	Factor	Location	Factor
Aklavik	1.39	Igloolik	1.65
Arctic Bay	1.67	Inuvik	1.25
Arctic Red River	1.36	Jean Marie River	1.35
Baker Lake	1.59	Lac La Martre	1.33
Broughton Island	1.62	Lake Harbour	1.57
Cambridge Bay	1.45	Nahanni Butte	1.51
Cape Dorset	1.52	Nanisivik - Strathcona Sound	1.61
Chesterfield Inlet	1.58		
Clyde River	1.69	Norman Wells	1.21
Coppermine	1.53	Pangnirtung	1.50
Coral Harbour	1.56	Paulatuk	1.62
Eskimo Point	1.52	Pelly Bay	1.75
Fort Franklin	1.40	Pine Point	1.01
Fort Good Hope	1.36	Pond Inlet	1.68
Fort Liard	1.47	Rankin Inlet	1.48
Fort McPherson	1.37	Rae/Edzo	1.07
Fort Norman	1.35	Rae Lakes	1.42
Fort Providence	1.01	Repulse Bay	1.59
Fort Resolution	1.09	Resolute	1.63
Fort Simpson	1.12	Sachs Harbour	1.61
Fort Smith	1.01	Sanikiluag	1.62
Frobisher Bay	1.42	Snowdrift	1.33
Gjoa Haven	1.70	Spence Bay	1.65
Grise Fiord	1.85	Tuktoyaktuk	1.40
Hall Beach	1.68	Whale Cove	1.57
Hay River	0.98	Wrigley	1.36
Holman Island	1.68	Yellowknife	1.00

From: Department of Public Works, Government of the NWT.

outfalls remote from the disinfection process site. No wastewater flow and strength equalization have been provided for the weak sewage at Dawson, as there are several sewer lines discharging at different points. A trunk sewer would be required to collect the flows at a central point for disinfection but this has not been included in the cost estimates.

5.2 Operating Costs

Because of the rising cost of fuel and dependency on costly imported fuel for generation of electricity in remote areas, energy costs were divided into two sub-categories, process requirements and heat and light. Process energy requirements were assumed to be entirely electrical and equivalent to the installed power of the disinfection equipment, mixing equipment and ventilation systems. This provided a conservative estimate as it is unlikely that equipment would be operating continuously at its rated load. Commercial rates for electrical power were obtained from the Northern Canada Power Commission for the five locations considered. The rates used in the calculation were the commercial government rates listed in Table 12.

TABLE 12 ELECTRICAL POWER COSTS IN NORTHERN COMMUNITIES

Location	Commercial Government (Cents/kWh)	Commercial Non-Government (Cents/kWh)
Aklavik, NWT	19.6	14.6
Dawson, YT	11.9	11.9 (General Service)
Frobisher Bay, NWT	13.4	13.4
Inuvik, NWT	9.5	9.0
Pangnirtung, NWT	16.8	14.6

Labour costs were based on estimated time commitment of qualified operators for routine monitoring or operating of equipment, occasional routine maintenance, and chemical supply changes. An average annual salary of $15 000 for an operator was assumed, based on the current salary scale for the operators of the Yellowknife water treatment and supply system.

Costs of chemicals were obtained from a single supplier f.o.b. Edmonton (western Arctic) or f.o.b. Montreal (eastern Arctic). Transportation costs for chemicals

were calculated from the freight rates presented in Table 10 and the annual chemical usage. Allowance was made for the cost of shipping containers to and from the site. Both purchase cost and transportation cost are presented in the cost tables in Appendix 1.

Maintenance includes both equipment maintenance and building maintenance. Equipment maintenance costs were generally assumed to be approximately 10 percent per annum of the total installed capital equipment cost. In the south, maintenance costs for rotating equipment generally are assumed to be eight percent and for non-rotating equipment five percent. The overall 10 percent figure was used to cover the additional costs of shipping of replacement equipment and travel and accommodation for outside service personnel.

Building maintenance was based on the Yellowknife cost of $3.77 per square metre multiplied by the maintenance cost factors presented in Table 14.

5.3 Process Alternatives

5.3.1 Chlorination. In costing each chlorination system, it was assumed that tanks would be steel with wood baffles, and cut and marked for field installation. Costs for the chlorinator itself were based on a manually controlled system using recycled effluent to feed the chlorinator venturi. The chlorinator sizing was based on two times design flow. No standby equipment was included. A flume was assumed to give adequate mixing prior to the contact chamber. Provision was made for the ventilation requirements for chlorine rooms as recommended in the WPCF Manual of Practice No. 8 (1967).

With the Purifax systems applied to holding tank and honey-bag wastes, costs for a factory assembled skid-mounted chlorinator/chlorine contact system were obtained from the Canadian supplier.

5.3.2 Chlorination-Dechlorination. The chlorination portion of this system was assumed to be identical with the chlorination systems already discussed (Section 4.1), with the exception that smaller contact tanks could be used due to the higher chlorine residual permitted following chlorine contact.

In costing the dechlorination portion of the system it was assumed that sulphur dioxide dosing was carried out in a chlorination of equal size to the one used in the chlorination stage. An additional allowance was made for a chlorine residual analyzer and feedback dosage controller. Costs of sulphur dioxide contact chambers were constant for each effluent type as the dechlorination reaction is nearly instantaneous provided good mixing is assured. A second flume was provided for mixing of the sulphur dioxide stream. No effluent re-aeration was deemed necessary.

TABLE 13 HEATING AND LIGHTING COSTS FOR SERVICE GARAGES IN THE NORTHWEST TERRITORIES

Settlement	Heat Fuel Cost per m^2	Light Fuel Cost per m^2	Total Cost per m^2	YK=1*
Aklavik	2.26	22.39	24.65	3.63
Arctic Bay	3.88	33.37	36.17	5.49
Arctic Red River	2.91	45.10	48.00	7.08
Baker Lake	4.31	24.76	29.06	4.29
Broughton Island	3.88	32.08	35.95	5.30
Cambridge Bay	4.31	25.73	30.03	4.43
Cape Dorset	6.24	25.73	31.97	4.71
Chesterfield Inlet	4.31	45.10	49.41	7.29
Clyde River	3.88	25.73	29.60	4.37
Coppermine	4.74	27.02	31.75	4.68
Coral Harbour	4.31	19.38	23.68	3.49
Eskimo Point	4.20	25.73	29.92	4.41
Fort Franklin	3.34	18.08	21.42	3.16
Fort Good Hope	2.80	24.76	27.56	4.06
Fort Liard	2.91	33.05	35.95	5.30
Fort McPherson	3.01	24.76	27.77	4.09
Fort Norman	2.69	19.38	22.07	3.25
Fort Providence	2.15	8.83	10.98	1.62
Fort Resolution	2.91	6.67	9.58	1.41
Fort Simpson	2.48	12.16	14.64	2.16
Fort Smith	2.37	4.31	6.67	0.99
Frobisher Bay	3.12	15.39	18.51	2.73
Gjoa Haven	5.81	29.60	24.65	3.63
Grise Fiord	3.88	28.31	32.19	4.75
Hall Beach	3.88	42.41	46.29	6.82
Hay River	2.05	4.31	6.35	0.94
Holman Island	4.31	38.54	42.84	6.32
Igloolik	4.20	25.73	29.92	4.41
Inuvik	2.26	10.87	13.13	1.94
Jean Marie River	2.80	38.64	41.44	6.11
Lac La Martre	3.88	38.64	42.52	6.27
Lake Harbour	6.24	33.37	39.61	5.84
Nahanni Butte	2.91	38.64	41.55	6.13
Norman Wells	1.72	12.81	14.53	2.14
Pangnirtung	3.88	19.38	23.25	3.43
Paulatuk	4.41	45.10	49.52	7.30
Pelly Bay	12.16	45.10	57.27	8.44
Pine Point	2.15	6.67	8.83	1.33
Pond Inlet	3.77	25.73	29.49	4.35
Rankin Inlet	4.09	23.79	27.80	4.11
Rae/Edzo	2.37	4.63	6.78	1.00
Rae Lakes	5.92	33.05	38.97	5.75
Repulse Bay	3.98	25.73	29.71	4.38
Resolute	5.27	17.33	22.60	3.33
Sachs Harbour	3.98	27.02	31.00	4.57
Sanikiluaq	6.24	45.10	51.35	7.57
Snowdrift	3.01	22.07	25.08	3.70
Spence Bay	5.38	25.73	31.11	4.60
Tuktoyaktuk	3.33	24.76	28.09	4.14
Whale Cove	4.63	34.66	38.29	5.80
Wrigley	2.80	22.07	24.87	3.67
Yellowknife	2.37	4.41	6.78	1.00

* These relative operating cost factors are obtained by designating Yellowknife as 1.00.

From: Armstrong et al (1977)

TABLE 14 MAINTENANCE COST FACTORS FOR SERVICE GARAGES IN THE NORTHWEST TERRITORIES

Settlement	Wage Factor	Freight Factor	Travel Factor	Total*
Aklavik	1.03	.10	.06	1.19
Arctic Bay	1.04	.20	.10	1.34
Arctic Red River	1.02	.21	.09	1.32
Baker Lake	1.03	.20	.09	1.32
Broughton Island	1.04	.19	.07	1.30
Cambridge Bay	1.03	.09	.07	1.19
Cape Dorset	1.04	.19	.04	1.27
Chesterfield Inlet	1.03	.18	.06	1.27
Clyde River	1.04	.20	.09	1.30
Coppermine	1.03	.10	.08	1.21
Coral Harbour	1.03	.20	.06	1.29
Eskimo Point	1.03	.16	.03	1.22
Fort Franklin	1.04	.16	.06	1.26
Fort Good Hope	1.02	.15	.05	1.22
Fort Liard	1.03	.15	.07	1.25
Fort McPherson	1.03	.11	.07	1.21
Fort Norman	1.02	.10	.03	1.15
Fort Providence	1.01	-.01	---	1.00
Fort Resolution	1.01	.03	.03	1.07
Fort Simpson	1.01	.03	.02	1.06
Fort Smith	---	.01	---	1.01
Frobisher Bay	1.03	.17	.03	1.23
Gjoa Haven	1.04	.20	.14	1.38
Grise Fiord	1.05	.25	.15	1.45
Hall Beach	1.03	.20	.06	1.29
Hay River	---	-.01	---	0.99
Holman Island	1.03	.18	.12	1.33
Igloolik	1.03	.20	.06	1.29
Inuvik	1.02	.07	.03	1.12
Jean Marie River	1.02	.05	.09	1.16
Lac La Martre	1.02	.07	.08	1.17
Lake Harbour	1.03	.20	.09	1.32
Nahanni Butte	1.03	.15	.07	1.25
Norman Wells	1.02	.05	.03	1.10
Pangnirtung	1.03	.18	.06	1.27
Paulatuk	1.03	.14	.09	1.26
Pelly Bay	1.04	.22	.16	1.42
Pine Point	---	---	---	1.00
Pond Inlet	1.04	.20	.10	1.34
Rankin Inlet	1.03	.17	.03	1.23
Rae/Edzo	1.01	.01	.01	1.03
Rae Lakes	1.03	.09	.09	1.21
Repulse Bay	1.03	.18	.12	1.33
Resolute	1.04	.22	.12	1.38
Sachs Harbour	1.04	.20	.12	1.36
Sanikiluaq	1.04	.20	.12	1.36
Snowdrift	1.02	.07	.07	1.16
Spence Bay	1.04	.18	.12	1.34
Tuktoyaktuk	1.03	.10	.06	1.19
Whale Cove	1.05	.18	.10	1.33
Wrigley	1.02	.05	.09	1.16
Yellowknife	---	---	---	1.00

* These relative maintenance cost factors are obtained by designating Yellowknife as 1.0.

From: Department of Public Works, NWT

5.3.3 Gamma Irradiation. As indicated in the cost data presented in Tables A-10 and A-11, Appendix 1, the largest single part of the capital costs for gamma irradiation of lagoon effluents and weak sewage is the initial purchase of the gamma source. Similarly annual purchase of replacement gamma rods is the most costly item in the operating costs. Costs were based on the calculated source requirement for each survival ratio, and the prices of cobalt-60 gamma source rods provided by AECL. Gamma source prices are shown in Table 15. Construction of the irradiators for all waste types is also more expensive than construction of contact chambers for the other disinfection alternatives as the structures must be built of concrete and set below ground level for radiation shielding. Wood pile foundations were assumed for each irradiator as well as insulation around the concrete structure to minimize heat loss.

TABLE 15 COSTS OF GAMMA SOURCES

Source Size (Mega curies)	Cost (cents/ curie)
<0.05	65.4
0.05 - 0.2	56.0
0.2 - 0.5	53.0
0.5 - 1.0	51.0
1.0 - 2.0	46.0
>2.0	43.9

Equipment costs included the costs for pumps, piping and electrical materials which would be supplied by the contractor, in addition to the mixers, de-ionizer system for the pool, and gamma source handling equipment which would be supplied by AECL. Quotations for the cost of this equipment were obtained from AECL for each waste type.

Installation costs included the costs for hook-up of piping and electrical works, as well as AECL's costs to install equipment and gamma sources. Maintenance costs were for pump and minor building maintenance. The AECL service costs for the replacement of gamma rods are included in the cost summaries as a separate item.

5.3.4 UV Radiation. The costs for the UV disinfection system were based on gravity flow in all-steel tanks equipped with steel weirs and launders, cut and marked for field

erection. It was assumed that reflector lamp holders would be used with the lamp ballasts mounted separately in an electrical panel. To prevent freezing problems and allow year round access and service, the weir system was enclosed in a building.

The 7500-hour service life of the UV tubes would require annual replacement of all UV tubes.

5.3.5 Ozonation. The ozonation system assumed in estimating ozonation costs consisted of a factory assembled skid mounted air supply/ozone generator unit and fibre reinforced plastic (FRP) contact columns. It was assumed that disinfected effluent could be recycled for ozone generator cooling. Building areas were based on the suppliers' recommended equipment layout, with the contact columns installed indoors to prevent freezing and permit greater ease of service during the winter. An additional building allowance was made for construction of a high roof to accommodate the contact columns.

5.3.6 Lime Disinfection. Capital costs for reactor clarifiers for lime disinfection of lagoon effluent, weak sewage and holding tank wastes were estimated from conventional concrete installations for southern application modified to provide for the use of all steel tanks. Construction, installation, engineering and equipment costs for steel water tanks as reported in the NWT cost summary were used as the basis for modifying reactor-clarifier costs. Capital costs for a prefabricated, package lime slurrying system were obtained from a manufacturer of portable lime systems. It was assumed that both the reactor-clarifier and lime slurry systems would be enclosed to minimize cold weather operating problems. For the lagoon effluent, weak sewage and holding tank waste lime disinfection proportional lime feed systems were assumed. However, direct manual application of lime to honey-bag wastes would be used, which would substantially reduce the cost.

5.4 Cost Comparison

5.4.1 Process Alternatives. In order to evaluate the relative capital and operating costs of the six disinfection alternatives for lagoon effluent and weak sewage, capital and operating costs were converted to the per person costs summarized in Tables 16, 17, 18 and 19. Similar comparisons for the disinfection alternatives for honey-bag and holding tank wastes are presented in Tables 20 and 21.

As indicated in Tables 16 and 18, capital costs for chlorination, chlorination-dechlorination, and UV disinfection of lagoon effluents and weak sewage are all very similar and roughly an order of magnitude lower than the capital costs for gamma

TABLE 16 CAPITAL COST COMPARISON FOR DISINFECTION OF LAGOON EFFLUENTS (IN DOLLARS)

Process	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Chlorination				
Total	40 800	49 350	75 700	119 800
Per person	16.32	19.74	30.28	47.92
Chlorination-Dechlorination				
Total	85 200	93 900	106 700	130 700
Per person	34.08	37.56	42.68	52.28
Ozonation				
Total	158 900	158 900	172 700	227 600
Per person	63.56	63.56	69.08	91.04
UV Radiation				
Total	41 200	81 000	115 800	NA
Per person	16.48	32.40	46.32	NA
Gamma-Radiation				
Total	333 400	767 200	1 320 900	2 083 400
Per person	133.36	306.88	528.36	835.36
Lime				
Total	807 000	807 000	807 000	807 000
Per person	322.80	322.80	322.80	322.80

irradiation and lime disinfection. Capital costs for ozonation are approximately twice those for the chlorination alternatives. The major differences in the capital costs of ozone and chlorination are the initial equipment costs and the costs due to the more complex installation of ozone.

Operating costs for disinfection of lagoon effluent and weak raw sewage follow a pattern similar to that for the capital costs as indicated in Tables 17 and 19. Chlorination, chlorination-dechlorination and UV irradiation are reasonably close in terms of operating cost, and are approximately an order of magnitude lower than those for lime

TABLE 17 ANNUAL OPERATING COST COMPARISON FOR DISINFECTION OF LAGOON EFFLUENTS (IN DOLLARS)

Process	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Chlorination				
Total	11 240	11 540	12 340	13 980
Per person	4.50	4.62	4.94	5.59
Chlorination-Dechlorination				
Total	22 030	22 580	22 300	24 680
Per person	8.81	9.03	9.32	9.87
Ozonation				
Total	47 310	47 310	54 350	76 770
Per person	18.92	18.92	21.74	30.71
UV Radiation				
Total	5 755	8 235	12 720	-
Per person	2.30	3.29	5.09	-
Gamma-Radiation				
Total	38 500	90 600	157 000	249 100
Per person	15.42	36.24	62.80	99.64
Lime				
Total	125 300	145 500	162 600	184 400
Per person	50.13	58.22	65.04	73.75

disinfection and gamma irradiation. Again, the operating costs for ozonation are roughly twice those for chlorination.

For honey-bag and holding tank wastes, gamma irradiation for disinfection is competitive both in terms of capital and operating costs as shown in Tables 20 and 21. For honey-bag wastes, the simple lime system is the least expensive at about half the cost of the gamma system. The Purifax process has a capital cost almost twice that of the gamma system, mainly as the result of high equipment costs.

TABLE 18 CAPITAL COST COMPARISON FOR DISINFECTION OF WEAK SEWAGE (IN DOLLARS)

Process	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Chlorination				
Total	52 800	70 800	98 600	204 600
Per person	99.62	133.58	186.04	386.04
Chlorination-Dechlorination				
Total	115 200	126 100	149 200	200 900
Per person	217.36	237.92	281.51	379.06
Ozonation				
Total	218 600	218 600	249 200	298 600
Per person	412.45	412.45	470.19	563.40
UV Radiation				
Total	62 200	90 600	199 700	NA
Per person	117.36	170.94	376.79	NA
Gamma-Radiation				
Total	493 700	1 448 500	2 774 250	4 543 420
Per person	931.51	2 733.02	5 234.43	8 572.49
Lime				
Total	928 800	928 800	928 800	928 800
Per person	1 752.45	1 752.45	1 752.45	1 752.45

For holding tank wastes gamma irradiation is the least costly of the disinfection processes, although it should be noted that the costs for all the systems fell within the 30 percent accuracy of the estimates. The lime system has a slight advantage in this case as it not only provides disinfection but also physical-chemical treatment for BOD and suspended solids removal as well.

In order to provide an overall comparison of the costs for each system, a total annual cost was calculated. Current cost estimation practice takes, as a rule-of-thumb, 10 percent of the total capital cost as the annual cost. The "cost recovery factor" (CRF)

TABLE 19 ANNUAL OPERATING COST COMPARISON FOR DISINFECTION OF WEAK SEWAGE (IN DOLLARS)

Process	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Chlorination				
Total	18 290	19 170	20 920	25 620
Per person	34.51	36.17	39.09	48.33
Chlorination-Dechlorination				
Total	34 670	35 270	36 570	39 570
Per person	65.42	66.55	69.00	74.66
Ozonation				
Total	79 820	79 820	101 530	141 600
Per person	150.60	150.60	191.57	267.17
UV Radiation				
Total	7 280	10 190	21 230	-
Per person	13.74	19.22	40.06	-
Gamma-Radiation				
Total	57 200	171 700	330 900	543 200
Per person	107.92	323.96	624.34	1 024.91
Lime				
Total	212 700	265 160	307 170	356 200
Per person	401.32	500.30	579.47	672.08

method was used to check this practice. When the cost of money is assumed at nine percent per annum over a 20-year amortization period, the annual cost would be 11 percent of the total capital cost. The 10 percent per annum figure was used for convenience in calculations; it was assumed to give data within the accuracy of these estimates. The total annual cost and the total per capita annual cost for lagoon effluent and weak sewage are presented in Tables 22 and 23, respectively. Similar comparisons for honey-bag and holding tank wastes are presented in Table 24.

TABLE 20 CAPITAL COST COMPARISONS FOR DISINFECTION OF HOLDING TANK AND HONEY-BAG WASTES (IN DOLLARS)

Process	Honey-Bag	Holding Tank
Chlorination (Purifax)		
Total	208 800	310 400
Per person	309.33	459.85
Chlorination-Dechlorination	NA	NA
Ozonation	NA	NA
UV Radiation	NA	NA
Gamma-Radiation		
Total	123 300 - 123 800	218 800 - 242 400
Per person	182.67 - 183.41	324.15 - 359.11
Lime		
Total	66 100	280 400
Per person	97.93	415.41

NA = not available

For disinfection of lagoon effluents and weak sewage, chlorination and UV irradiation are similar in annual costs for survival ratios of 5×10^{-3} or greater. Chlorination has the advantage, however, in that it is a more flexible system and can provide much higher levels of disinfection (lower survival ratios) than can UV, as the effectiveness of UV is limited by the ability of the UV radiation to penetrate particulate matter in the effluents. Chlorination-dechlorination costs are one and one-half to two times greater than chlorination alone due to the increased equipment, chemical and maintenance costs.

The cost for ozonation of lagoon effluent and weak sewage is roughly four times that for chlorination alone due to both higher equipment and much higher energy costs.

Both lime disinfection and gamma irradiation are about an order of magnitude higher in terms of total annual cost than chlorination, which makes these two alternatives uncompetitive for use in the disinfection of lagoon effluent and weak sewage.

TABLE 21 ANNUAL OPERATING COST COMPARISON FOR DISINFECTION OF HONEY-BAG AND HOLDING TANK WASTES (IN DOLLARS)

Process	Honey-Bag	Holding Tank
Chlorination (Purifax)		
Total	18 420	41 630
Per person	27.51	61.67
Chlorination-Dechlorination	NA	NA
Ozonation	NA	NA
UV Radiation	NA	NA
Gamma-Radiation	NA	NA
Total	24 970 - 25 030	33 800 - 36 500
Per person	36.99 - 37.08	50.07 - 54.07
Lime		
Total	23 650	47 440
Per person	35.04	70.28

NA = not available

For holding tank and honey-bag wastes, gamma irradiation, Purifax chlorination and lime treatment are similar in terms of total annual cost. It should be noted, however, that the per capita costs make these processes unattractive to small communities with a limited economic base. For honey-bag wastes, the simpler alternative of disposal directly to a sludge pit, as suggested by Heinke and Prasad (1976), followed by direct lime application is probably preferable. Disposal of holding tank wastes to a long-detention lagoon, with disinfection of the effluent being practised during annual discharge of supernatant, may be a more attractive alternative than the direct disinfection processes described. This may be especially the case as per person holding tank waste volumes increase with the conversion to pumped water systems in each house.

If disinfection of holding tank wastes is to be undertaken following the methods outlined in this study, pilot facilities for lime and gamma irradiation should be constructed to allow these methods to be directly compared.

TABLE 22 COMPARISON OF ANNUAL COSTS FOR DISINFECTION OF LAGOON EFFLUENTS (IN DOLLARS)

Process	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Chlorination				
Total	15 300	16 500	19 900	25 960
Per person	6.13	6.59	7.97	10.38
Chlorination-Dechlorination				
Total	30 600	32 000	34 000	37 800
Per person	12.22	12.79	13.59	15.10
Ozonation				
Total	63 200	63 200	71 600	99 500
Per person	25.28	25.28	28.65	39.81
UV Radiation				
Total	9 875	16 300	24 300	NA
Per person	3.95	6.53	9.72	NA
Gamma-Radiation				
Total	71 900	167 320	289 000	458 000
Per person	28.76	66.93	115.64	183.18
Lime				
Total	206 000	226 000	243 000	265 000
Per person	82.41	90.50	97.32	106.03

TABLE 23 COMPARISON OF ANNUAL COSTS FOR DISINFECTION OF WEAK SEWAGE (IN DOLLARS)

Process	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Chlorination				
Total	23 600	26 250	30 580	46 100
Per person	44.47	49.53	57.69	86.93
Chlorination-Dechlorination				
Total	46 200	47 900	51 500	59 700
Per person	87.16	90.34	97.15	112.57
Ozonation				
Total	101 680	101 680	126 500	171 500
Per person	191.85	191.85	238.65	323.51
UV Radiation				
Total	13 500	19 250	41 200	NA
Per person	25.48	36.31	77.74	NA
Gamma-Radiation				
Total	106 570	316 600	608 300	997 500
Per person	201.07	597.26	1 147.78	1 182.16
Lime				
Total	305 600	358 000	400 000	449 000
Per person	576.57	675.55	754.72	847.23

TABLE 24 COMPARISON OF ANNUAL COSTS FOR DISINFECTION OF HONEY-BAG AND HOLDING TANK WASTES (IN DOLLARS)

Process	Honey-Bag	Holding Tank
Chlorination		
Total	39 300	72 700
Per person	58.22	107.66
Chlorination-Dechlorination		
Total	-	-
Per person	-	-
Ozonation		
Total	-	-
Per person	-	-
UV Radiation		
Total	-	-
Per person	-	-
Gamma-Radiation		
Total	37 300 - 37 400	55 700 - 60 700
Per person	55.26 - 55.42	82.49 - 89.98
Lime		
Total	30 260	75 500
Per person	44.83	111.82

5.4.2 East-West Cost Comparison. In order to assess the applicability of the cost estimates to different geographic areas in the Arctic, and the effects of different transportation corridors, cost estimates for disinfection of lagoon effluent, holding tank wastes and honey-bag wastes were prepared. These estimates assumed that identical systems would be installed in the Baffin (eastern) region as in the Inuvik (western) region.

To convert "western" costs to "eastern" costs the following assumptions were made:

- engineering costs would remain at 15 percent of the total capital cost;
- equipment costs would change only as a result of different shipping costs;
- installation costs would remain unchanged;
- construction costs would be increased based on the ratio of construction cost factors in Table 11;
- energy costs would be factored according to the appropriate electrical power and fuel rates;
- operator labour costs would remain the same;
- chemical purchase costs would remain unchanged while transportation costs would be factored according to the freight rates in Table 10;
- maintenance costs would remain the same.

Examples of converting "western" costs to "eastern" costs are presented in Tables 25 and 26, respectively. Table 25 shows estimates for systems applicable to Inuvik costed for Frobisher Bay and Table 26 shows estimates for systems applicable to Aklavik costed for Pangnirtung. Table 27 compares the average annual costs for disinfection of lagoon effluents at Inuvik and at Frobisher Bay. As indicated, the cost of disinfection in the eastern Arctic averages approximately eight percent higher than in the western Arctic, with a range from four to 15 percent. It should be noted that the ratio of the Northern Community Indexes (NCI's) for the two communities is 1.08 (see Table 10). This compares favourably to estimated costs for disinfection and suggests that the costs for disinfection of effluents with equivalent flow and strength at other locations may be obtained by the factoring method using the NCI.

The cost comparison for ozonation at Frobisher Bay and Inuvik illustrates the effect of high energy costs on annual costs. Electrical power costs are 40 percent higher in Frobisher Bay than Inuvik, and a power intensive process such as ozonation will reflect this difference. Capital costs for ozonation increased by approximately five percent in the west to east transfer, whereas operating costs increased by about 20 percent due

TABLE 25 COMPARISON OF ANNUAL COSTS FOR DISINFECTION OF LAGOON EFFLUENT AT FROBISHER BAY (IN DOLLARS)

Process	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Chlorination				
Total	16 470	17 800	21 630	28 400
Per person	6.59	7.12	8.65	11.36
Chlorination-Dechlorination				
Total	32 540	34 090	36 310	40 480
Per person	13.02	13.64	14.52	16.19
Ozonation				
Total	71 650	71 650	82 350	117 350
Per person	28.66	28.66	32.94	46.94
UV Radiation				
Total	10 500	17 300	26 350	-
Per person	4.20	6.92	10.54	-
Gamma-Radiation				
Total	777 90	173 200	295 200	483 900
Per person	31.11	69.28	118.00	193.56
Lime				
Total	206 800	247 700	267 200	291 800
Per person	82.72	99.08	106.88	116.72

TABLE 26 COMPARISON OF ANNUAL COSTS FOR DISINFECTION OF HONEY-BAG AND HOLDING TANK WASTES AT PANGNIRTUNG (IN DOLLARS)

Process	Honey-Bag	Holding Tank
Chlorination (Purifax)		
Total	39 580	72 310
Per person	58.64	107.12
Chlorination-Dechlorination		
Total	-	-
Per person	-	-
Ozonation		
Total	-	-
Per person	-	-
UV Radiation		
Total	-	-
Per person	-	-
Gamma-Radiation		
Total	36 630 - 38 735	59 760 - 69 800
Per person	56.83 - 57.39	88.53 - 96.03
Lime		
Total	30 080	76 560
Per person	44.56	113.42

TABLE 27 COMPARISON OF AVERAGE ANNUAL COSTS FOR DISINFECTION OF LAGOON EFFLUENTS AT INUVIK AND FROBISHER BAY

Process	Average Annual Cost ($)		
	Inuvik	Frobisher Bay	Frobisher Bay: Inuvik
Chlorination	19 400	21 100	1.09
Chlorination-Dechlorination	33 600	32 850	1.07
Ozonation	74 400	85 800	1.15
UV Radiation	16 800	18 000	1.07
Gamma-Radiation	246 600	257 500	1.04
Lime	235 000	253 000	1.08
		Average	1.08

entirely to the increase in energy costs. This resulted in the 15 percent overall increase in annual costs.

The relatively low increase in costs for gamma irradiation (for Frobisher compared to Inuvik) is due to the high initial cost of the gamma source, which is not dependent on geographic location.

In contrast to the cost for disinfection of lagoon effluents, cost differences for disinfection of holding tank and honey-bag wastes at Aklavik and Pangnirtung were insignificant, as indicated in Table 28. While there were increases in capital costs, lower power and fuel costs in Pangnirtung offset the increased capital costs to a large extent and resulted in only a one to two percent average increase in annual cost. This is substantially lower than the 12 percent increase expected on the basis of the NCI's for each location.

The Northern Community Index was developed from the Valeurs Polaires (VAPO) index of nordicity (Hamelin, 1972), modified by construction cost factors, population base and transportation costs. The VAPO number was based on geographic and socio-economic factors such as temperature, precipitation, latitude, population, degree of economic development, and transportation. The NCI should therefore reflect the costs to

TABLE 28 COMPARISON OF HONEY-BAG AND HOLDING TANK WASTE DISINFECTION COST ESTIMATES FOR AKLAVIK AND PANGNIRTUNG (IN DOLLARS)

Process	Aklavik	Pangnirtung	Pangnirtung: Aklavik
a) Honey-Bag Wastes			
Chlorination (Purifax)	39 300	39 600	1.01
Gamma Radiation	37 400	38 700	1.03
Pumped Lime	30 300	30 100	0.99
		Average	1.01
b) Holding Tank Wastes			
Chlorination (Purifax)	72 700	72 300	0.99
Gamma Radiation	58 200	62 300	1.07
Pumped Lime	75 500	76 600	1.01
		Average	1.02

Arctic communities associated with the various transportation corridors, and construction requirements dictated by geographical differences.

Power costs should be directly related to transportation costs in the Arctic because of the importation of fuel. However, the power cost for Aklavik (obtained from the Northern Canada Power Corporation) is 17 percent higher than for Pangnirtung, while transportation costs to Pangnirtung are 26 percent higher than to Aklavik. Under these conditions the use of the NCI for factoring disinfection costs would not apply as demonstrated in Table 28.

As the NCI is a composite of many cost factors, if the contribution of those cost factors to any project is not equivalent to the contribution of that factor to the index, then the use of the NCI for cost factoring will be invalidated. Gamma irradiation exemplifies how high capital costs (for gamma source purchase) dominate the effects of different transportation costs and prevent the use of the NCI. Similarly, the large contribution of power costs to the annual costs of ozonation dominate the capital costs, so that factoring using the NCI would be invalid.

However, if the limitations of the NCI are given consideration, the NCI may prove to be a useful tool in cost factoring between communities.

5.4.3 Comparison with Disinfection in Southern Canada. A comparison of capital, operating and total annual costs was undertaken for disinfection of lagoon effluents to establish the difference in costs between Arctic and southern Canada. The comparison was undertaken only for lagoon effluents, as this is the only northern wastewater type considered which has a southern counterpart of significant volume.

Costs for the southern alternatives were based on conventional construction and operation practices and reflect current costs in the Great Lakes/St. Lawrence basin. The following differences in the basis of costing should be noted:

1) All tanks were assumed to be concrete rather than steel, with the exception of the ozone alternative, for which FRP columns were assumed as in the Arctic.
2) All process tanks were assumed to be open to the atmosphere rather than covered.
3) Separate control buildings of the minimum size specified by the equipment manufacturer were assumed.
4) Engineering was assumed to be 10 percent of the cost in the south, compared with 15 percent in the Arctic.
5) Electrical power at a cost of 2¢/kWh was assumed.
6) Operator labour costs remained unchanged.
7) Chemical purchase price remained unchanged.

Table 29 summarizes the average capital, operating and total operating costs for each process alternative at Inuvik and at a southern community for the disinfection of same lagoon effluent. On the average, capital costs were found to be 2.25 times higher in Inuvik than in the south, while operating costs were 1.67 times higher. The overall total annual cost was 1.8 times in Inuvik than in the south.

In general, the increases in capital costs were higher than those for operating costs. However, some specific exceptions should be noted. For an energy intensive process such as ozonation, the increase in operating costs was greater than that for capital costs. For lime disinfection, which is construction intensive, the increase in capital costs was higher than the increase in operating costs and was by far the highest increase observed. In contrast, gamma irradiation, which has very large fixed capital and operating costs for purchase of the radiation source, showed only a small (1.08 times) increase in both capital and operating costs between a southern location and the Arctic.

TABLE 29 COMPARISON OF AVERAGE CAPITAL, OPERATING AND TOTAL ANNUAL COSTS FOR DISINFECTION OF LAGOON EFFLUENT IN ARCTIC AND SOUTHERN CANADA (IN DOLLARS)

Process	Inuvik	South	Inuvik: South
Chlorination			
Capital	71 400	24 800	2.88
Operating	12 300	6 360	1.93
Annual	19 440	8 840	2.20
Chlorination-Dechlorination			
Capital	104 100	43 100	2.42
Operating	23 100	15 700	1.47
Annual	33 500	20 000	1.68
Ozonation			
Capital	179 500	120 000	1.50
Operating	56 400	28 300	1.99
Annual	74 350	40 300	1.84
UV Radiation			
Capital	79 300	41 420	1.91
Operating	8 900	5 350	1.66
Annual	16 830	9 490	1.77
Gamma Radiation			
Capital	1 127 500	1 042 000	1.08
Operating	133 800	125 000	1.07
Annual	246 550	229 200	1.08
Lime			
Capital	807 000	219 000	3.68
Operating	154 500	82 175	1.88
Annual	235 200	104 100	2.26

6 IMPACT ASSESSMENT

6.1 Approach

In this chapter two matrices are presented: the first deals with the impact of the construction and operation of the different disinfection alternatives on the environment; the second compares process related variables such as safety and health hazards, operator skill requirements and maturity of technology development and cost. The matrices deal primarily with disinfection of lagoon effluent and weak sewage as their volumes are substantially larger and their direct discharge method of disposal has a more pronounced effect than discharges of honey-bag or holding tank wastes to a waste pit.

In Table 30 the environmental impact matrix for the six disinfection alternatives is presented. Magnitude of impact is ranked from low to high. No distinction has been made between adverse or beneficial impacts. In some instances both are possible as with chlorination, which causes a beneficial reduction in bacterial numbers for downstream users, but which may degrade water quality through the introduction of chlorinated organics. Impacts marked with an asterisk indicate areas where little data are available and further investigation is required to assess the potential impact. Blank spaces indicate no significant impact.

The impacts are predicted from experience with the various disinfection alternatives and from available literature. Construction impacts are based on the size of the project and the amount of potentially disruptive activity. Similarly, the impact of operating the disinfection facility is ranked in Table 30 for the six alternative processes, based on the man-power and material requirements detailed in the costing section of this report. The impacts are also based on the specific environmental factors discussed in this chapter and consider process design.

The process and cost matrix, presented in Table 31, was prepared to assist in the comparison of operation of the various disinfection alternatives. Again, the ranking has been based primarily on the disinfection of lagoon effluent and weak sewage. Table 31 summarizes information presented both in this and in previous chapters. It has been prepared from experience with the six disinfection processes and from published literature. Each disinfection alternative has been ranked in magnitude on a scale of 1 to 5 for each of the seven process-related factors. The ranking or magnitude is shown in the upper left of the appropriate box, together with a "+" or "-" sign to indicate whether the factor has a desirable (positive) or undesirable (negative) effect on potential for

TABLE 30 ENVIRONMENTAL IMPACT MATRIX

PROCESS	ACTIVITY	EFFECT	PHYSICAL/CHEMICAL			BIOLOGICAL				SOCIO-ECONOMIC			
			Water Quality	Air Quality	Land Form & Erosion	Aquatic Flora and Fauna	Waterfowl	Vegetation	Wildlife	Safety	Health	Employment	Land Use
CHLORINATION	CONSTRUCTION	Earth Work	○		◑			○	○	○		○	
		Mechanical/Structural							○	○		○	
	OPERATION	Transport			○					○	○		
		Plant Processes								○	○	○	
		Gaseous Effluent		○					○	○	○		
		Liquid Effluent	●			◑	○				◑		○
CHLORINATION-DECHLORINATION	CONSTRUCTION	Earth Work	○		○	○		○	○	○		○	
		Mechanical/Structural							○	○		○	
	OPERATION	Transport			○					○		○	
		Plant Processes								○	○	○	
		Gaseous Effluent		○					◑	○	○		
		Liquid Effluent	◑			○	○				◑		○
OZONATION	CONSTRUCTION	Earth Work	○		○	○		○	○	○		○	
		Mechanical/Structural							○	○		○	
	OPERATION	Transport											
		Plant Processes								○	○	○	
		Gaseous Effluent		○					○	○	○		
		Liquid Effluent	☆			○					☆		○
ULTRAVIOLET IRRADIATION	CONSTRUCTION	Earth Work	○		○	○		○	○	○		○	
		Mechanical/Structural							○	○		○	○
	OPERATION	Transport											
		Plant Processes								○		○	
		Liquid Effluent	☆							○	○		○
GAMMA IRRADIATION	CONSTRUCTION	Earth Work	○		◑	○		○	○	○		○	
		Mechanical/Structural							○	○		○	
	OPERATION	Transport							○	○	○	○	
		Plant Processes									○	○	
		Liquid Effluent	☆								☆	○	○
LIME	CONSTRUCTION	Earth Work	○		◑	○		◑	○	○		○	
		Mechanical/Structural			◑				○	○		○	
	OPERATION	Transport			◑			○		○		○	
		Plant Processes								○		◑	
		Liquid Effluent	○		○	○			○	○		○	○
		Solid Effluent			●			◑	◑	○		○	●

○ Low
◑ Moderate
● High
No Effect
☆ Unknown

TABLE 31 PROCESS AND COST MATRIX*

IMPORTANCE FACTOR	Equipment Reliability 4	Technological Reliability 1	Climatic Effects 1	Level of Operator Skill 3	Outside Assistance 2	Energy Consumption 4	Disinfection Reliability 5	TOTAL	Capital Cost	Operating Cost	Indirect Cost
Chlorination	+3 / +12	+5 / +5	-1 / -1	-2 / -6	-2 / -4	-2 / -8	+3 / +15	+13	-1	-1	-3
Chlorination/ Dechlorination	+3 / +12	+4 / +4	-1 / -1	-2 / -6	-2 / -4	-2 / -8	+3 / +15	+12	-2	-2	-3
Ozonation	+2 / +8	+3 / +3	-1 / -1	-3 / -9	-3 / -6	-5 / -20	+3 / +10	-5	-3	-3	-3
UV Irradiation	+4 / +16	+1 / +1	-1 / -1	-1 / -3	-1 / -2	-1 / -8	+1 / +5	+8	-1	-1	-2
Gamma Irradiation	+4 / +16	+2 / +2	-1 / -1	-1 / -3	-1 / -2	-1 / -4	+5 / +25	+34	-5	-5	-3
Lime	+1 / +4	+1 / +1	-2 / -2	-5 / -15	-4 / -8	-3 / -12	+2 / +10	-22	-4	-4	-5

* Based on disinfection of lagoon effluents and weak sewage

Magnitude

+2 / +8

Magnitude X Importance

1 Low
3 Moderate
5 High

\+ Positive or beneficial effect
\- Negative or deleterious effect

application of the disinfection alternative in the Arctic. Each of the seven factors has then been ranked according to its importance in an Arctic application, and this rank of importance is multiplied by magnitude to obtain the number in the lower right of each box. These numbers have been summed to obtain an overall process-related ranking.

Direct costs such as capital and operating costs are ranked according to the data presented in section 5.4. The indirect costs consider those resulting from the environmental impact of disinfection in the Arctic. The indirect or induced cost of environmental impact is extremely difficult to quantify. A simple approach assumes cost is related to impact and therefore greatest impacts will generally have the highest indirect cost. One can arrive at an indirect cost by assigning values of 1, 3 and 5 to the low, moderate, and high impact rankings, respectively shown in Table 30. The unknown category is assigned a value of 5. The numbers shown in Table 31 represent the sum of the individual impacts for each disinfection alternative rounded to the nearest 10 and divided by 10. Importance of cost has not been ranked and will be site specific, and will include local economic base and specific environmental factors.

The following sub-sections discuss several of the salient features summarized in the two matrices. The overall matrix analysis is summarized at the end of this chapter.

6.2 Chlorination and Chlorination-Dechlorination

Chlorination is the most widely used wastewater disinfection process. As such, hazards associated with operation of a chlorination facility are well known and the necessary safety precautions well-documented (WPCF, 1967). Chlorination-dechlorination is less widely used but the safety practices are identical to those for chlorination. The technology of chlorine disinfection is well-developed and requires relatively low level of operator skill.

Similarly, the technology of dechlorination is well developed, utilizes a similar type of equipment, and requires only slightly more operator training to operate. Both processes have demonstrated reliability in water and wastewater disinfection in southern Canada. If chlorine and sulphur dioxide were to be used, then heated facilities or a special vaporizer will be required in winter as chlorine boils at -35°C and sulphur dioxide sublimes at 10°C.

Wastewater chlorination is known to be a significant source of chlorinated organics entering the aquatic eco-system. Jolley (1975) demonstrated that one percent of the total chlorine applied in disinfection of secondary effluents reacts to form chlorinated organic compounds. Further, it has been demonstrated that chlorination of wastewaters

significantly increases the toxicity to aquatic organisms. Dechlorination substantially reduces the quantity of chloramines formed by chlorination of wastewaters, resulting in elimination of chlorine-induced toxicity (Martens and Servizi, 1975). However, no indication of changes in the quantity of chlorinated organics has been reported.

Russian studies (Skidal'skaya, 1969) on the disinfection of drinking water have indicated that mutagenesis of E. Coli does result from chlorination at dosages commonly used to disinfect. The typical E. coli found in chlorinated water showed altered cultural and biochemical properties but remained non-virulent.

6.3 Gamma Irradiation

Application of gamma irradiation for water and wastewater disinfection has been limited primarily because of the cost of radioactive sources. However, in recent years it has been studied extensively as a means of disinfecting sewage sludges prior to land application. Because of relatively limited full-scale application, the technology cannot be considered to have reached as high a state of maturity as other alternatives.

In Canada, all radiation sources are supplied by AECL, and must conform to strict standards for handling, transfer and use of radioactive materials. Commerical irradiators of the types available in Canada through AECL are designed so that average daily operator exposure to radiation conforms to the limits set for the general public by the International Commission on Radiation Protection. According to information obtained from AECL, sufficient shielding is provided so that the international standard for the general public is not exceeded at the surface of the irradiator. This results in actual operator exposures of substantially less than the international standard for the general public.

The irradiators considered in this report are shielded in accordance with AECL requirements by concrete housing and earthworks. As handling of all radioactive materials is undertaken by AECL personnel, operator exposure to abnormal levels of radiation is not possible. Operation is restricted to operation and maintenance of external pumps and values. Consequently, operation skill requirements are low.

Gamma irradiation is not expected to have any significant environmental impact. Production of radioactive byproducts is highly unlikely because the disintegration energy of the cobalt-60 source is low relative to other elements. Only one or two uncommon elements have lower energies and they alone would be susceptible to neutron displacement by gamma radiation from the cobalt-60 source (AECL, 1978).

Although gamma irradiation has been used as laboratory tool for inducing mutagenesis in micro-organisms, little evidence exists to suggest that any increase in virulence will result from disinfection by gamma irradiation. Mutagenesis normally results in loss of function and specifically loss of virulence (Lamanna and Mallette, 1976). As a specific example, Epps and Idziak (1970) reported that a strain of Salmonella exposed to sub-lethal doses of gamma radiation altered into strains of lesser public health significance, signifying reduced virulence. Sivinsky and Neuhauser (1978) reported that at the gamma radiation dosages necessary for disinfection, the probability of mutation is very high. However, the resultant strains generally have multiple mutations, are difficult to grow under ideal laboratory conditions, and would not be able to compete in the environment. A survey by Sivinsky and Neuhauser (1978) of researchers working with gamma radiation indicated that the formation of virulent organisms by gamma-induced mutation is highly unlikely and not a significant factor in public health.

Cesium-137 has been considered as an alternative to cobalt-60 as a gamma source for commercial irradiators. The isotope is readily available as a by-product from fission reactors and has a longer half-life than cobalt-60. Because only one photon of gamma radiation is released per disintegration as compared to two for cobalt-60, and as energy per photon is about half that of cobalt-60, the effectiveness of cesium-137 as a disinfecting agent is lower than that of cobalt-60 on a per curie basis. Cesium-137, as obtained from most sources, contains about 10 percent cesium-134, which is a higher energy, shorter half-life isotope. Consequently, encapsulation for cesium is designed for the higher energy cesium-134 isotope and reduces the available radiation from the cesium rod. Although the initial cost of cesium-137 has been quoted as 10 cents per curie in the U.S., the much higher curie requirement for an equivalent amount of available radiation does not give cesium any significant cost advantages over cobalt-60.

Despite the limited experience with irradiators for disinfection, the simplicity of the system and the fail-safe mechanisms which are required for use of radioactive material ensure a high level of operating reliability. Because of the energy level of the gamma radiation, penetration of all wastewater constituents is achieved, ensuring uniform and consistent disinfection throughout the wastewater volume despite variations in suspended solids content. Provision for thawing frozen honey-bags will be required, but no other modifications are necessitated by the Arctic climate. Man-power requirements are as low as for the equivalent chlorination system, as indicated in Chapter 5.

6.4 Ultraviolet Irradiation

Although the technology for drinking water disinfection by UV is well-developed, considerable research is currently underway in both Canada and the US evaluating the use and efficiency of ultraviolet irradiators for wastewater disinfection. As with gamma irradiation, the process itself is simple and reliable from an operating standpoint. However, unlike gamma the lower energy UV radiation is unable to penetrate suspended solids particles to provide consistent disinfection. The technology of wastewater disinfection with UV is still in the developmental stage.

There are few documented operating or environmental hazards associated with UV disinfection. Safety requirements are minimal, only proper eye-shields and electrical insulation being required when servicing the UV tubes when in operation. Operator skill requirements are similarly low, as are man-power requirements (Chapter 5). No climatic effects are expected other than the need to provide a heated enclosure so that the UV tubes operate near their optimum temperature.

Like gamma radiation, UV light has been used extensively as a research tool for inducing mutagenesis in micro-organisms (Lamanna and Mallette, 1975). UV induced mutations also are characterized by a loss of function, and consequently loss of virulence. The creation of more virulent strains is highly unlikely.

6.5 Ozone

Ozone currently is finding much wider acceptance in the disinfection of both drinking water and secondary treated wastewater. The technology is well developed although not as thoroughly researched as chlorination. Because of the complexity of the ozonation and associated processes, more skilled man-power is required than for the other disinfection alternatives with the exception of lime. The complexity of the system also results in less reliable operation than chlorination, or chlorination-dechlorination. The safety requirements for ozone and chlorine are similar. Both are toxic gases, although ozone is generated on-site and chlorine is stored in cylinders and transported to the site. Climatic conditions will not affect the ozonation process, except that cold weather will enhance the efficiency of air drying and ozone dissolution. Little information is available on the environmental impact of ozonated effluents. It has been shown (Cairns et al, 1977) that ozonated effluents containing residual ozone are toxic to fish, but that the toxicity dissipates rapidly due to the reactivity and rapid decay of ozone in water. Although no data were found on the mutagenicity of ozone, it may be speculated that mutations will arise during ozonation, because of the strong oxidizing character of ozone.

6.6 Lime Disinfection

Application of lime specifically for disinfection by increasing pH has not been reported for a full-scale system. While the technology of lime application for phosphorus removal has been developed and applied in full-scale systems, the problems associated with the handling and disposal of the additional lime required to achieve pH levels greater than 10.5 or 11.0 required for disinfection have not been addressed. Based on the Ontario experience with lime for phosphorus removal, the use of lime for disinfection would require considerable skilled man-power for operation and maintenance, and would be subject to more operating problems than other disinfection alternatives.

Neutralization of the effluent would be required following lime disinfection to avoid impacts associated with pH changes in the low alkalinity, poorly-buffered Arctic waters.

6.7 Impact Summary

Ultraviolet disinfection appears to have the least impact on the environment, based on available information (Table 30). It should be noted that the full extent of the effects of UV irradiation on water quality are not well-documented as yet and further research is required. However, chlorination-dechlorination and ozonation are not substantially different from UV disinfection in environmental impact, and the fate of by-products of these disinfection processes is better researched than for UV. Chlorination and gamma irradiation are ranked next, based on the known environmental impact of chlorination, the relatively unknown effects of radiation on water quality and the significant impact of construction or a radiation facility. Lime has a major undesirable environmental impact during both the construction and operation of a system.

On the basis of the seven process-related factors shown in Table 31, chlorination, chlorination-dechlorination and UV irradiation are similar and rank below gamma irradiation. Ozone ranks lower, due primarily to its high energy requirements. Lime ranked the lowest.

When cost is considered in the evaluation, the ultimate ranking will depend on individual site characteristics. If it is assumed that the use of conventional technology is the most desirable approach, then the preferred process is that which is the least expensive, the most reliable and the most environmentally acceptable. On this basis, chlorination-dechlorination may be chosen for disinfection of lagoon effluents and weak sewage. However, UV has lower cost and environmental impact but cannot be relied upon

to provide consistent disinfection. If filtration is provided as a pre-treatment step prior to UV disinfection, lower survival ratios could be achieved at the expense of significantly higher capital and operating costs. Gamma irradiation, although the best process from an operational standpoint and relatively low in terms of environmental impact, has significantly higher costs and therefore cannot be considered the most desirable disinfection process for lagoon effluents and weak sewage in the Arctic. Although honey-bag and holding tank wastes were not evaluated separately in this section, the conclusions drawn from the process (not cost) matrix of Table 31 will apply. Similarly, the nature of their environmental impacts will be the same but of lower relative magnitude.

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REFERENCES

Armstrong, B., J. Cameron, and V. Christensen, "Water and Sanitation Project Costs - A Consolidation of Historical Cost Information", Department of Local Government, Government of the Northwest Territories (1977).

AECL (Atomic Energy of Canada Limited, Ottawa, Ontario) personal communication, (1978).

Cairns, V.W., F.A. Tonelli, and A. Netzer, "The Acute Lethality of Disinfection Alternatives", Environment Canada. Environmental Protection Service, Technology Transfer Notes on Disinfection (April 20, 1977).

Clark, N.A., G. Berg, P.W. Kabler, and S.L. Chang, "Human Enteric Viruses in Water: Source, Survival and Removability", Advances in Water Pollution Research, Vol. 2, p525 MacMillan, Toronto (1964).

Diaper, E.W.J., "Practical Aspects of Water and Wastewater Treatment by Ozone", Ozone in Water and Wastewater Treatment, F.L. Evans ed., Ann Arbor Science Publishers Inc., p145 (1972).

Epps, N.A., and E.S. Idziak, "Radiation Treatment of Foods II. Public Health Significance of Irradiation Recycled Salmonella", Applied Microbiology, 19(2), 338 (1970).

Geldreich, E.E., H.F. Clark, and C.B. Huff, "A Study of Pollution Indicators in a Waste Stabilization Pond", J. Water Pollut. Contr. Fed., 36, 1372 (1964).

Gordon, R.C., C.V. Davenport, and B.H. Reid, "Chlorine Disinfection of Treated Wastewater in a Baffled Contact Chamber at Less Than 1°C", Symposium on Wastewater Treatment in Cold Climates, Water Pollution Control Directorate, Environment Canada, Report EPS 3-WP-74-3 (1974).

Grabow, W.O.K., "Literature Survey: The Use of Bacteria as Indicators of Faecal Pollution in Water", National Institute for Water Research, Pretoria, South Africa CSIR Special Report O/WAT 1 (1970).

Hamelin, L.E., "A Circumpolar Index", in Canada's Changing North, W.C. Wonders ed., McLelland and Stewart Ltd., Toronto (1971).

Heinke, G.W. and W.W. Baldwin, "Evaluation of Municipal Services at Dawson and Old Crow, Yukon Territory", for Northern Science Research Group, Department of Indian Affairs and Northern Development (1973).

Heinke, G.W., H.K. Miyamoto, and N.A. Jacobsen, "Evaluation of the Sewage Lagoon at Inuvik, NWT", for Northern Science Research Group, Department of Indian Affairs and Northern Development (1972).

Heinke, G.W., and D. Prasad, "Disposal of Human Wastes in Northern Areas", for Environmental Protection Service, Environment Canada (1976).

Jolley, R.L. "Chlorine-containing Organic Constituents in Chlorinated Effluents", J. Water Pollut. Contr. Fed., 47, 601 (1975).

Kenner, B.A., N.A. Clark, and P.W. Kabler, "Fecal Streptococci II: Quantification of Streptococci in Feces", Am. J. Pub. Hlth., 50, 1553 (1960).

Kinman, R.N., "Ozone Disinfection of Wastewaters at Low Temperatures", Symposium on Wastewater Treatment in Cold Climates, Water Pollution Control Directorate, Environment Canada, Report EPS 3-WP-74-3 (1974).

Lamanna, C., and M.F. Mallette, Basic Bacteriology, 3rd Edition, Williams and Wilkins Co., Baltimore, Maryland, (1965).

Martens, D.W., and J.A. Servizi, "Dechlorination of Municipal Sewage Using Sulphur Dioxide", International Pacific Salmon Fisheries Commission Progress Report No. 32 (1975).

Morrison, S.M., and K.L. Martin, "Lime Disinfection of Sewage at Low Temperatures", Symposium on Wastewater Treatment in Cold Climates, Water Pollution Control Directorate, Environment Canada, Report EPS 3-WP-74-3 (1974).

Murphy, K.L., "Gamma Radiation as an Effective Disinfectant", Water and Pollution Control, 112, 24 (1974).

Nebel, C., P.C. Unangst, R.D. Gottschling, "Ozone Disinfection of Secondary Effluents", Industrial Water and Pollution Conference and Exposition, The Water and Wastewater Equipment Manufacturers Association, Chicago (March 14-16, 1973).

Oliver, B.G., and J.H. Carey, "A Scale-up Investigation of Ultraviolet Disinfection as an Alternative to Chlorination of Sewage Effluents", Can. J. Chem. Eng., 53, 711 (1975).

Oliver, B.G., and E.G. Cosgrove, "The Disinfection of Sewage Treatment Plant Effluents Using Ultraviolet Light", Can. J. Chem. Eng., 53, 170 (1975).

Peters, M.S., and K.D. Timmerhaus, Plant Design and Economics for Chemical Engineers, 2nd Edition, McGraw Hill, Toronto p. 98 (1969).

Selleck, R.E., H.F. Collins, and G.C. White, "Problems in Obtaining Adequate Disinfection in Wastewater Treatment Plants", Proceedings of National Specialty Conference on Disinfection, University of Massachusetts, Amherst (July 8-10, 1970).

Senn, C.L. "Coliform Organisms as an Index of Water Safety", Proc. ASCE, Journal of the Sanitary Engineering Division, 87 (SA-6), 41 (1961).

Sivinsky, H.D., and S. Neuhauser, Sandia Laboratories, Albuquerque, New Mexico, personal communication, (1978).

Skidal'skaya, M.A., "New Data on the Mechanism of Disinfection of Drinking Water by Chlorine and Gamma Radiation", J. Hyg. Sanitation, 34 (11), 193 (1969).

Smith D.W., and P.W. Given, "Ozone Disinfection of Dilute Low-Temperature Wastewater", Third Congress of the International Ozone Institute, Paris, France (May 4-6, 1977).

U.S. EPA, "Disinfection of Wastewater", U.S. Environmental Protection Agency, Task Force Report EPA-430/9-75-012 (March 1976).

Vajdic, A.H., Gamma Irradiation Treatment of Secondary Sewage Effluent, Ontario Ministry of the Environmental Research Report W59 (1974).

Water and Pollution Control, "77/78 Directory and Environmental Handbook" (November 1977).

Water Pollution Control Directorate, "Interim Guidelines for Wastewater Disposal in Northern Canadian Communities", Policy and Planning Report EPS-2-WP-74-1, Environment Canada (1974).

WPCF, Sewage Treatment Plant Design, Manual of Practice No. 8, Water Pollution Control Federation (1967).

White, G.C., Handbook of Chlorination, Van Nostrand Reinhold, New York (1972).

APPENDIX A

COST SUMMARIES FOR

DISINFECTION PROCESS ALTERNATIVES

TABLE A-1 COST SUMMARY FOR CHLORINATION OF LAGOON EFFLUENT AT INUVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	6 100	7 400	11 350	18 000
Equipment	12 700	13 800	17 800	25 100
Installation	8 800	9 700	13 400	20 000
Construction	13 200	18 450	33 150	56 700
TOTAL	40 800	49 350	75 700	119 800
Operating Costs				
Energy				
- process	670	670	670	670
- heat, light, ventilation	1 000	1 200	1 600	2 300
Labour	4 000	4 000	4 000	4 000
Chemicals				
- purchase	1 960	1 960	1 960	1 960
- delivery	910	910	910	910
Maintenance	2 700	2 800	3 200	4 140
TOTAL	11 240	11 540	12 340	13 980

TABLE A-2 COST SUMMARY FOR CHLORINATION OF WEAK SEWAGE AT DAWSON (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	7 900	10 600	14 800	30 700
Equipment	14 600	16 900	22 200	35 200
Installation	10 500	12 600	15 500	27 500
Construction	19 800	30 700	46 100	111 200
TOTAL	52 800	70 800	98 600	204 600
Operating Costs				
Energy				
- process	860	860	860	860
- heat, light, ventilation	1 300	1 670	2 180	4 400
Labour	4 000	4 000	4 000	4 000
Chemicals				
- purchase	6 530	6 530	6 530	6 530
- delivery	3 000	3 000	3 000	3 000
Maintenance	2 600	3 110	4 150	6 830
TOTAL	18 290	19 170	20 720	25 620

TABLE A-3 COST SUMMARY FOR CHLORINATION-DECHLORINATION OF LAGOON EFFLUENT AT INUVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	12 700	14 100	16 000	19 600
Equipment	23 800	24 200	26 900	31 400
Installation	17 400	19 800	20 200	24 200
Construction	31 300	35 800	43 600	55 500
TOTAL	85 200	93 900	106 700	130 700
Operating Costs				
Energy				
- process	1 340	1 340	1 340	1 340
- heat, light, ventilation	950	1 100	1 320	1 700
Labour	9 000	9 000	9 000	9 000
Chemicals				
- purchase	4 140	4 140	4 140	4 140
- delivery	1 900	1 900	1 900	1 900
Maintenance	4 700	5 100	5 600	6 600
TOTAL	22 030	22 580	23 300	24 680

TABLE A-4 COST SUMMARY FOR CHLORINATION-DECHLORINATION OF WEAK SEWAGE AT DAWSON (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	17 300	18 900	22 400	30 100
Equipment	28 300	29 650	34 100	41 900
Installation	19 800	21 000	25 000	32 000
Construction	49 800	56 550	67 700	96 900
TOTAL	115 200	126 100	149 200	200 900
Operating Costs				
Energy				
- process	1 720	1 720	1 720	1 720
- heat, light, ventilation	1 500	1 700	2 000	2 900
Labour	9 000	9 000	9 000	9 000
Chemicals				
- purchase	11 450	11 450	11 450	11 450
- delivery	5 200	5 200	5 200	5 200
Maintenance	5 800	6 200	7 200	9 300
TOTAL	34 670	35 270	36 570	39 570

TABLE A-5 COST SUMMARY FOR CHLORINATION (Purifax) OF HONEY-BAG AND HOLDING TANK WASTES AT AKLAVIK (IN DOLLARS)

	Honey-Bag	Holding Tank
Capital Costs		
Engineering	31 300	46 600
Equipment	120 000	185 000
Installation	20 000	27 400
Construction	37 500	51 400
TOTAL	208 800	310 400
Operating Costs		
Energy		
- process	830	6 300
- heat, light, ventilation	1 000	1 000
Labour	3 000	15 000
Chemicals		
- purchase	700	700
- delivery	390	330
Maintenance	12 500	18 300
TOTAL	18 420	41 630

TABLE A-6 COST SUMMARY FOR OZONATION OF LAGOON EFFLUENT AT INUVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	23 800	23 800	25 900	34 100
Equipment	66 400	66 400	74 300	101 000
Installation	16 200	16 200	20 000	40 000
Construction	52 500	52 500	52 500	52 500
TOTAL	158 900	158 900	172 700	227 600
Operating Costs				
Energy				
- process	16 560	16 560	22 100	39 420
- heat, light, ventilation	1 950	1 950	1 950	1 950
Labour	15 000	15 000	15 000	15 000
Chemicals				
- purchase	-	-	-	-
- delivery	-	-	-	-
Maintenance	13 800	13 800	15 300	20 400
TOTAL	47 310	47 310	54 350	76 770

TABLE A-7 COST SUMMARY FOR OZONATION OF WEAK SEWAGE AT DAWSON (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	32 800	32 800	37 400	44 800
Equipment	97 000	97 000	111 000	146 000
Installation	28 000	28 000	40 000	47 000
Construction	60 800	60 800	60 800	60 800
TOTAL	218 600	218 600	249 200	298 600
Operating Costs				
Energy				
- process	42 470	42 470	61 580	94 850
- heat, light, ventilation	2 450	2 450	2 450	2 450
Labour	15 000	15 000	15 000	15 000
Chemicals				
- purchase	-	-	-	-
-delivery	-	-	-	-
Maintenance	19 900	19 900	22 500	29 300
TOTAL	79 820	79 820	101 530	141 600

TABLE A-8 COST SUMMARY FOR UV IRRADIATION OF LAGOON EFFLUENT AT INUVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	5 200	10 300	14 500	-
Equipment	9 000	20 100	23 000	-
Installation	15 000	35 000	45 000	-
Construction	12 000	15 600	33 300	-
TOTAL	41 200	81 000	115 800	-
Operating Costs				
Energy				
- process	370	615	1 690	-
- heat, light, ventilation	325	420	900	-
Labour	3 000	3 000	3 000	-
UV Tube Replacement				
- purchase	600	1 000	2 600	-
-delivery	60	100	250	-
Maintenance	1 400	3 100	4 280	-
TOTAL	5 755	8 235	12 720	-

TABLE A-9 COST SUMMARY FOR UV IRRADIATION OF WEAK SEWAGE AT DAWSON (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	7 800	11 400	25 100	-
Equipment	13 000	18 800	41 500	-
Installation	22 500	34 100	76 800	-
Construction	18 900	26 300	56 300	-
TOTAL	62 200	90 600	199 700	-
Operating Costs				
Energy				
- process	1 060	1 870	4 880	-
- heat, light, ventilation	500	870	2 300	
Labour	3 000	3 000	3 000	-
UV Tube replacement				
- purchase	1 300	2 300	6 000	-
- delivery	150	200	500	-
Maintenance	1 270	1 950	4 550	-
TOTAL	7 280	10 190	21 230	-

TABLE A-10 COST SUMMARY FOR GAMMA IRRADIATION OF LAGOON EFFLUENT AT INUVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	26 300	26 300	26 300	26 300
Equipment	59 100	59 100	59 100	59 100
Installation	23 000	23 000	23 000	23 000
Construction	93 000	93 000	93 000	93 000
Gamma-Source	132 000	565 800	1 119 500	1 887 000
TOTAL	333 400	767 700	1 302 900	2 088 400
Operating Costs				
Energy				
- process only	6 500	6 500	6 500	6 500
Labour	6 000	6 000	6 000	6 000
Gamma Source Replacement				
- purchase	15 840	67 900	134 300	226 400
- delivery	4 500	4 500	4 500	4 500
Maintenance	5 700	5 700	5 700	5 700
TOTAL	38 540	90 600	157 000	249 100

TABLE A-11 COST OF SUMMARY FOR GAMMA IRRADIATION OF WEAK SEWAGE AT DAWSON (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	26 900	26 900	26 900	26 900
Equipment	59 600	59 600	59 600	59 600
Installation	26 600	26 600	26 600	26 600
Construction	93 000	93 000	93 000	93 000
Gamma-Source	287 600	1 242 370	2 568 150	4 337 320
TOTAL	493 700	1 448 500	2 774 250	4 543 420
Operating Costs				
Energy				
- process only	6 500	6 500	6 500	6 500
Labour	6 000	6 000	6 000	6 000
Gamma-Source Replacement				
- purchase	34 500	149 000	308 200	520 500
- delivery	4 500	4 500	4 500	4 500
Maintenance	5 700	5 700	5 700	5 700
TOTAL	57 200	171 700	330 900	543 200

TABLE A-12 COST SUMMARY FOR GAMMA IRRADIATION OF HONEY-BAG WASTES AT AKLAVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	16 000	16 000	16 000	16 000
Equipment	64 100	64 100	64 100	64 100
Installation	19 800	19 800	19 800	19 800
Construction	22 800	22 800	22 800	22 800
Gamma-Source	600	750	900	1 050
TOTAL	123 300	123 450	123 600	123 800
Operating Costs				
Energy				
- process only	2 100	2 100	2 100	2 100
Labour	15 000	15 000	15 000	15 000
Gamma Source Replacement				
- purchase	71	89	108	125
- delivery	3 800	3 800	3 800	3 800
Maintenance	4 000	4 000	4 000	4 000
TOTAL	24 971	24 989	25 008	25 030

TABLE A-13 COST SUMMARY FOR GAMMA IRRADIATION OF HOLDING TANK WASTES AT AKLAVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	26 500	26 500	26 500	26 500
Equipment	60 100	60 100	60 100	60 100
Installation	23 500	23 500	23 500	23 500
Construction	93 000	93 000	93 000	93 000
Gamma Source	15 700	24 200	31 400	39 250
TOTAL	218 800	227 300	234 500	242 400
Operating Costs				
Energy - process only	6 500	6 500	6 500	6 500
Labour	15 000	15 000	15 000	15 000
Gamma-Source Replacement				
- purchase	2 000	3 000	3 800	4 700
- delivery	4 500	4 500	4 500	4 500
Maintenance	5 800	5 800	5 800	5 800
TOTAL	33 800	34 800	35 600	36 500

TABLE A-14 COST SUMMARY FOR LIME DISINFECTION OF LAGOON EFFLUENT AT INUVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	121 000	121 000	121 000	121 000
Equipment	231 000	231 000	231 000	231 000
Installation	254 000	254 000	254 000	254 000
Construction	201 000	201 000	201 000	201 000
TOTAL	807 000	807 000	807 000	807 000
Operating Costs				
Energy				
- process	13 000	13 000	13 000	13 000
- heat, light, ventilation	2 000	2 000	2 000	2 000
Labour	32 000	32 000	32 000	32 000
Chemicals				
- purchase	19 980	29 670	37 620	48 180
- delivery	35 050	45 570	54 670	65 890
Maintenance	23 300	23 300	23 300	23 300
TOTAL	125 330	145 540	162 590	184 370

TABLE A-15 COST SUMMARY FOR LIME DISINFECTION OF WEAK SEWAGE AT DAWSON (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	139 300	139 300	139 300	139 300
Equipment	249 000	249 000	249 000	249 000
Installation	266 000	266 000	266 000	266 000
Construction	274 500	274 500	274 500	274 500
TOTAL	928 800	928 800	928 800	928 800
Operating Costs				
Energy				
- process	23 000	23 000	23 000	23 000
- heat, light, ventilation	3 500	3 500	3 500	3 500
Labour	32 000	32 000	32 000	32 000
Chemicals				
- purchase	45 790	54 360	70 320	90 400
- delivery	73 125	117 000	143 000	172 000
Maintenance	35 300	35 300	35 300	35 300
TOTAL	212 715	265 160	307 120	356 200

TABLE A-14 COST SUMMARY FOR LIME DISINFECTION OF LAGOON EFFLUENT AT INUVIK (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	121 000	121 000	121 000	121 000
Equipment	231 000	231 000	231 000	231 000
Installation	254 000	254 000	254 000	254 000
Construction	201 000	201 000	201 000	201 000
TOTAL	807 000	807 000	807 000	807 000
Operating Costs				
Energy				
- process	13 000	13 000	13 000	13 000
- heat, light, ventilation	2 000	2 000	2 000	2 000
Labour	32 000	32 000	32 000	32 000
Chemicals				
- purchase	19 980	29 670	37 620	48 180
- delivery	35 050	45 570	54 670	65 890
Maintenance	23 300	23 300	23 300	23 300
TOTAL	125 330	145 540	162 590	184 370

TABLE A-15 COST SUMMARY FOR LIME DISINFECTION OF WEAK SEWAGE AT DAWSON (IN DOLLARS)

	Survival Ratio			
	5×10^{-1}	5×10^{-2}	5×10^{-3}	5×10^{-4}
Capital Costs				
Engineering	139 300	139 300	139 300	139 300
Equipment	249 000	249 000	249 000	249 000
Installation	266 000	266 000	266 000	266 000
Construction	274 500	274 500	274 500	274 500
TOTAL	928 800	928 800	928 800	928 800
Operating Costs				
Energy				
- process	23 000	23 000	23 000	23 000
- heat, light, ventilation	3 500	3 500	3 500	3 500
Labour	32 000	32 000	32 000	32 000
Chemicals				
- purchase	45 790	54 360	70 320	90 400
- delivery	73 125	117 000	143 000	172 000
Maintenance	35 300	35 300	35 300	35 300
TOTAL	212 715	265 160	307 120	356 200

TABLE A-16 COST SUMMARY FOR LIME DISINFECTION OF HONEY-BAG AND HOLDING TANK WASTES AT AKLAVIK (IN DOLLARS)

	Honey-Bag	Holding Tank
Capital Costs		
Engineering	9 900	42 100
Equipment	12 700	72 700
Installation	19 600	72 000
Construction	23 900	93 600
TOTAL	66 100	280 400
Operating Costs		
Energy		
- process	4 500	9 400
- heat, light, ventilation	930	3 100
Labour	15 000	15 000
Chemicals		
- purchase	310	2 420
- delivery	700	5 320
Maintenance	2 210	12 200
TOTAL	23 650	47 440

APPENDIX B

ABBREVIATIONS, SYMBOLS AND DEFINITIONS

ABBREVIATIONS, SYMBOLS AND DEFINITIONS

BOD_5	5-day biochemical oxygen demand
curie	quantity of any radioactive isotope undergoing 3.7×10^{10} disintegrations per second
ε	efficiency of irradiation system
einstein	6.0×10^{23} quanta or photons of electromagnetic radiation
krad	kilorad = 1 000 rads (see rad)
megacurie	10^6 curies (see curie)
MOE	Ontario Ministry of the Environment
NTU	Northern Technology Unit
photon	unit quantity of energy in an electromagnetic field as postulated in the quantum theory
rad	equivalent to absorption of 100 ergs of energy by 1 g of material (for ^{60}CO, 85 curies deliver 1 megarad to 454 g in 1 hour)
Survival Ratio	ratio of number of viable organisms remaining after disinfection to number initially present
UV	ultraviolet
y/y_o	survival ratio